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ASTRONOMICAL BOOKS FOR THE USE OF STUDENTS.

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FOR POPULAR ASTRONOMY.

To conclude our series of articles we proceed to consider the last three divisions given in POPULAR ASTRONOMY for January. In the final division no mention will be made of the works of Chauvenet and Oppolzer, because they are so well known that a statement of their contents is quite unnecessary. So many books which would come in the first division have been published in recent years that it has been necessary to make a selection, and also to restrict mention to modern works.

Lockyer: The Sun's Place in Nature; Macmillan & Co., publishers; $2.75.

This is a re-publication of a series of lectures delivered in 1894, and published in *Nature* at that time. The chief points of interest are the story of the discovery of helium on the Earth, the argument for the evolution theory as applied to nebulæ, and the strong attempt to prove that many of the stars are now rising in temperature. The author's repeated attacks upon the work of Sir Wm. Huggins unfortunately mar the otherwise effective presentation of his own theories.

Young: The Sun; revised edition (1895); D. Appleton & Co., publishers; pp. 363; $2.00.

Proctor's work on this subject is quite out of date, and Ball's "Story of the Sun," while attractive, must yield the palm to Professor Young's work, which is thoroughly brought down to the date of its revision. The first three chapters are devoted to the distance and dimensions of the Sun, the apparatus for studying its manifestations of energy, and its spectrum. The next four chapters treat of the spots, the chromosphere and the corona. The two following ones discuss the Sun's light, heat and constitution. A seven page note on helium concludes the book.

Todd: Total Eclipses of the Sun; Little, Brown & Co., publishers; $1.00.

The new edition of Mrs. Todd's book brings the story of total

eclipses down through that of January 1898. It gives an account of the progress of knowledge about eclipses from the earliest times to the present. The aims of eclipse parties are well stated, and the present methods of observation set forth. Charts are given of the paths of future eclipses till 1937.

Elger: The Moon; Geo. Philip & Son, publishers; pp. 173; 5sh.

The late Mr. T. G. Elger was the director of the lunar section of the British Astronomical Association, and a most devoted selenographer. The book aims to give a full description and map of the principal physical features of the Moon's surface. It is the best lunar hand-book of moderate price. The map is 18 inches in diameter and may be obtained separately.

Nasmyth & Carpenter: The Moon; Scribners, publishers: pp. 213: $9.00.

This expensive book, which is noteworthy for its extremely beautiful pictures of lunar scenery, is the result of more than thirty years of labor on the part of the authors. They studied the Moon with powerful telescopes, made careful drawings, and then constructed accurate models of lunar craters. These were photographed. The text considers the origin of lunar details, the classes of lunar formations, the conditions which a hypothetical inhabitant would experience, and the worth of the Moon to man.

Flammarion: La Planète Mars; Gauthier-Villars et Fils, publishers; pp. 608.

The work is divided into two parts. The first embraces 488 pages; it sets forth and discusses the observations of the planet from 1636 to 1892. This space of time is divided into three periods; at the close of the treatment of each period is given a summary of the conclusions to be derived from the observations made during it. The second part of the book, which comprises about 100 pages, gives the author's final conclusions about the planet's orbit, dimensions, rotation, surface features and atmosphere. The illustrations number over 600, and are almost exclusively from drawings of the planet. There is no other work on Mars to be compared with this one, for exhaustiveness.

Lowell: Mars; Houghton, Mifflin & Co., publishers: pp. 217: $2.50.

Mr. Lowell has given a discussion of the physical conditions on Mars, for the purpose of throwing light upon the question of the existence of intelligent beings there. The book was inspired by a special study of the planet made at Flagstaff, Arizona. The chief

subjects considered are the atmosphere, water, canals, and oases. The numerous reproductions of drawings of Mars are the most beautiful to be found in any popular work on the planet. Mr. Lowell's conclusion is that it is "probable that upon the surface of Mars we see the effects of local intelligence."

Guillemin: The World of Comets; Sampson, Low, Marston, Searle & Rivington, publishers: pp. 548: about $4.00.

Guillemin's interesting work is now twenty-five years old; it was done into English by Jas. Glaisher. It is so complete a popular description of comets and their peculiarities that it quite defies analysis in the space at our disposal. It is the leading work on its subject.

Lockyer: The Meteoritic Hypothesis: Macmillan & Co., publishers; pp. 560; $5.25.

The meteoritic hypothesis is the theory that celestial bodies are composed of meteors, more or less thickly crowded together. The book gives in detail the observations and experiments which led the author to promulgate the theory. The observations are spectroscopic. The first half of the book contains a good deal of interesting popular matter about meteors and comets. The remainder is for the spectroscopic specialist.

Darwin: The Tides; Houghton, Mifflin & Co., publishers; pp. 378.

Mr. G. H. Darwin (son of the great naturalist) is well known as one of the chief living authorities on the subject of the tides. In 1897 he delivered a course of lectures at the Lowell Institute, from which the present volume took its rise. After discussing terrestrial tides very thoroughly the author devotes four chapters to tidal friction, and its effects on the evolution of celestial systems. After these chapters is the concluding one, which treats of the rings of Saturn. Mr. Darwin's book easily distances any other popular work on the tides, and is of absorbing interest.

Lockyer: The Dawn of Astronomy; Macmillan & Co., publishers; pp. 432; $3.00.

Here we find a study of the mythology and temple worship of the ancient Egyptians, with reference to their connection with astronomy. The book is finely illustrated, and appeals to the specialist in astronomic lore.

Clerke: The System of the Stars; Longmans, Green & Co., publishers; pp. 440; $7.00.

No other work in our language handles this topic so thor-

oughly and satisfactorily. The rapid advances made by sidereal astronomy in recent years are set forth in lucid and graphic style. Theories of the construction of the sidereal universe are well discussed. The demand for so valuable a book ought to be sufficient to warrant the publishers in putting a new and cheaper edition upon the market.

Gore: The Visible Universe; Macmillan & Co., publishers; pp. 340.

Unfortunately this is out of print, probably because its discussions are not strictly popular, though non-mathematical. To the student, however, the book fills quite a valuable niche, since most of it is devoted to an elaborate discussion of theories of the form of the visible universe, and of the distribution of stars in it.

Flammarion: Les Étoiles et les Curiosités du Ciel; Marpon et Flammarion, publishers; pp. 792.

The first part of this large royal octavo volume comprises 587 pages and gives in great detail a description of each of the principal constellations, and also of all easily observable objects in each constellation. The nature of these descriptions may be judged by the following quotation from the table of contents, with reference to Taurus, to which 34 pages are devoted.

"Rich region of the sky—The Pleiades in history—the Hyades —Taurus the first sign of the zodiac—The sun Aldebaran—movement of its companion—names given to the Pleiades—critical examination of all the observations—proper motions of the Pleiades—of the Hyades—the nebula in Taurus."

Part II, which covers nearly 200 pages, contains tabulated statements of various kinds, in a profusion which quite defies analysis in the space at our command.

Frost: Astronomical Spectroscopy; Translated from the German of Dr. J. Scheiner, and revised with the author's sanction; Ginn & Co., publishers; pp. 450; $5.00.

This is the best book in English on the subject of which it treats. While nearly seven years have passed since its publication, during which large advances in astronomical spectroscopy have been made, the book is of great value. Part First, embracing 110 pages, is devoted to spectroscopic apparatus. Part Second, which is but 40 pages in length, treats of Kirchhoff's law and Doppler's principle. Part Third embraces over 200 pages, and is devoted to the results of spectroscopic observations on the heavenly bodies. The 64 pages of Part Fourth are devoted

to spectroscopic tables. An appendix follows containing a bibliography which includes most of the memoirs and papers prior to 1894.

Ambronn: Handbuch der Astronomischen Instrumentenkunde; Julius Springer (Berlin) publisher; 2 vols.; pp. 1276; 60 marks.

This work is fairly encyclopaedic in range, and is one of the best specimens of German thoroughness. There are seven main divisions, three of which are in Vol. I. The first deals with minor parts of instruments, such as screws, levels, verniers, reading microscopes, artificial horizons, etc. The second treats of clocks of all sorts, and chronometers, together with the electrical devices used in them. The third division is concerned with the three principal parts of most instruments, namely the axes, the telescope, and the graduated circles. The discussion of the refracting telescope is very interesting, as there is a full description of the methods of selecting, figuring, combining and mounting the lenses in their cell. Reflecting telescopes in their varied forms are also minutely described. The fourth division is devoted to the typical forms of micrometers, with which the author classes the heliometer. In the fifth division belong instruments for special purposes, such as heliostats, siderostats, photographic refractors, measuring engines, photometers, and spectroscopic apparatus. The sixth division is very extensive and treats of all the forms of the principal instruments which grace observatories. Here we find sextants, universal instruments, transit circles, chronographs, and equatorials of all sorts described in almost bewildering detail. The seventh and last division of this great work describes the piers on which instruments are placed, and the structures which shelter them. There are 1185 cuts of the objects described, 393 of which are of complete instruments. Methods of using instruments, and of determining the errors to which they are subject are given in such detail that the work may well claim to be a manual of the art of astronomical observation.

TELESCOPIST'S MANUALS.

Serviss: Astronomy with an Opera-glass; D. Appleton & Co., publishers; pp. 154; $1.50.

The idea embodied in the title is faithfully worked out. The author gives hints for the choice of a good opera-glass (the new Goerz binocular was not then on the market) and describes the many enjoyable views of the heavens which it will yield. The

more prominent celestial objects are described, and maps of the constellations are given, together with directions for picking them out in the sky.

Fowler: Popular Telescopic Astronomy; Geo. Philip & Son, publishers; 2 sh.

The subtitle is "How to make a 2-inch Telescope and what to see with it." Any desired parts of the telescope can be purchased of the publishers of the book. A review in *Nature* says, "The whole of the work explained can be easily understood and readily performed. The book is practicable as well as practical; every description in it can be carried out, every observation described bears the impress of experience. Astronomy will gain more by the publication of this little volume than by the issue of a score of works of a descriptive character."

Mee: Observational Astronomy; new edition; Western Mail, Limited, publishers; pp. 113; 2 sh. 6 d.

This is a very unique little book, and is admirable for a student or amateur to use, if he has a small telescope, and wishes to become interested in what it will reveal. The author assumes that the reader wants to see things with his little glass, to make pictures of them, and to understand the real nature of what he is looking at. The book is illustrated by a host of small pictures, many of which are thumb-nail sketches of well-known living astronomers.

Gibson: The Amateur Telescopist's Hand-book; Longmans, Green & Co., publishers; pp. 163; introduction price, $0.95.

The first third of this admirable little book is devoted to the telescope, and tells how to test, care for, and use it. Then follow two chapters giving special directions for observing the Sun, Moon, etc. The second half of the book is an explanatory catalogue of 468 celestial objects, arranged according to the constellations in which they are found. Preceding this catalogue are a few pages giving the prices of small telescopes and their accessories.

Gore: The Scenery of the Heavens; Roper & Drowley, publishers; pp. 320; $4.00.

The subtitle of this work is "A Popular Account of Astronomical Wonders," and sums up its contents well. For the book is chiefly devoted to a description of the principal objects of interest in the sky. The chapter on meteors was contributed by Mr. Denning, the foremost authority on that subject.

Denning: Telescopic Work for Starlight Evenings; Taylor & Francis, publishers; pp. 361; $2.00.

In the first three chapters the methods of testing and handling a telescope are set forth. The relative merits of refractors and reflectors are discussed. The rest of the book contains descriptive matter concerning the heavenly bodies, special prominence being given to the subject of meteors.

Webb: Celestial Objects for Common Telescopes; Longmans, Green & Co., publishers; 2 vols., pp. 513; $3.50.

For many years the earlier editions of this work were considered as containing exceedingly complete and valuable lists of interesting telescopic objects. The fifth edition, revised and enlarged by T. E. Espin, distances all competitors in its field. The first volume tells how to use a telescope in visual, photographic and spectroscopic observations and contains chapters on the Sun, Moon, planets, comets and meteors. These chapters have been contributed by specialists, and the one on the Moon, which is accompanied by a large folding map, is specially complete. Volume II is given up to double stars, clusters, nebulæ, stars with remarkable spectra, and variables; it contains descriptions of over 2,000 such objects.

Proctor: Half Hours with the Stars; G. P. Putnam's Sons, publishers; pp. 38; $2.00.

There are a dozen maps in quarto, showing the aspect of the heavens throughout the year. The text explains how to find the star-groups. As only a few stars fainter than the fourth magnitude are shown, the maps are well adapted to constellation study.

Klein: Star Atlas; E. and J. B. Young & Co., publishers; pp. 72 aside from maps and plates; $2.00.

A dozen maps, each 12x9 inches, exhibit all the stars not fainter than the sixth magnitude between the north pole and 30° of south declination. The stars are black on a white background, their names being printed in red. There are no dotted lines connecting the chief stars of each constellation. Preceding the maps is a sixty page list of interesting telescopic objects, each of which is well described. The atlas is one of the best in our language.

Upton: Star Atlas; Ginn & Co., publishers; $2.00.

This atlas is in folio, so that the large maps measure about 15x13 inches; there are six of these, four covering the region

from + 40° to — 40° of declination, while the other two contain respectively the northern and southern circumpolar regions. Each circumpolar map embraces the area within 50° of the pole. These six large maps contain all stars not fainter than the sixth magnitude, besides the more important of the clusters, nebulæ, double stars, red stars and variables. The background of each is white; the stars are black, and the outlines of the historic constellation figures are lightly drawn in pale blue. The boundaries between the constellations are marked by heavy blue dotted lines. Preceding these maps are six corresponding small ones, containing only the chief stars of each constellation; the stars in each group are joined together by lines, a characteristic figure being thus made, to facilitate learning the groups. Twenty-nine pages of explanatory text precede the maps; in these pages are discussed the historical growth of the present constellation system, the designations of stars, and the accurate photometric method of estimating magnitudes. There are also (in these pages) descriptive lists of clusters, nebulæ, variables and doubles, the objects in each list being arranged in the order of their right ascensions. The atlas has been prepared with the special needs of teachers and students in view.

Colas: Celestial Planisphere; Poole Bros., publishers; $3.00.

This is the best planisphere which the writer has ever seen. It is nearly 19x23 inches, and almost all stars visible to the naked eye between the north celestial pole and 50° of south declination are depicted upon it; the chief nebulæ are also shown. A celestial handbook of 110 pages accompanies it, in which are to be found descriptions of the chief objects of interest in each constellation. The handbook costs $2.00 extra.

Text Books on Mathematical Astronomy.

Doolittle: A Treatise on Practical Astronomy as Applied to Geodesy and Navigation; John Wiley and Sons, publishers; pp. 652; $4.00.

Professor Doolittle's work begins with a 69 page treatment of the method of least squares, followed by an excellent discussion of interpolation. Then come two chapters, one of which is on the systems of spherical coördinates in ordinary use, and their transformations; the other treats of parallax, refraction and the dip of the horizon. Nearly 400 pages are next devoted to methods of determining time, latitude, longitude and azimuth with the ordinary forms of portable instruments. The final

chapter of the book treats of precession, nutation, aberration and proper motion. The book is admirably adapted to the use of students, and may also serve as a field manual.

Campbell: The Elements of Practical Astronomy, second edition, revised and enlarged; Macmillan & Co., publishers; pp. 259; $2.00.

Professor Campbell has written to meet the wants of University students and engineers, and has produced a manual which has stood the test of the class room. All is given that is essential for the student who wishes to make the usual observations with the sextant, transit, zenith telescope, and position micrometer attached to an equatorial. Observations with a surveyor's transit for time, latitude and azimuth are also explained.

Barlow and Bryan: Elementary Mathematical Astronomy; Clive & Co., publishers; pp. 442; 8sh, 6d.

The authors have not written a manual of practical astronomy but have endeavored to give a simple mathematical treatment of those subjects which every descriptive astronomy mentions. The student's knowledge is supposed not to extend beyond trigonometry. However, the last three chapters, which are upon gravitational astronomy, involve rudimentary notions about the ellipse, which are furnished in an appendix. Exercises in goodly number, are scattered through the book.

Greene: An Introduction to Spherical and Practical Astronomy; Ginn & Co., publishers; pp. 158; $1.50.

After the usual problems on the transformation of coördinates, the author devotes six chapters to the determination of time, latitude and longitude with the transit and sextant. The two remaining chapters describe methods for finding the azimuth of a line, and for finding the figure and dimensions of the Earth. A 32 page appendix gives the elements of the method of least squares.

Merriman: Elements of Precise Surveying and Geodesy; John Wiley & Sons, publishers; pp. 261; $2.50.

After an introductory chapter, giving the elementary notions of the method of least squares, the author devotes four chapters to field operations of precise surveying. Then follow chapters on "Spherical Geodesy," "Spheroidal Geodesy," "Geodetic Coördinates and Projections," "Geodetic Triangulation," and "The Figure of the Earth." Eighty-one problems are scattered through the book. The usual clearness and precision of Professor Merriman's writing are maintained in the present work.

Merriman: Text Book on the Method of Least Squares; enlarged edition; John Wiley & Sons, publishers; pp. 228; $2.00.

This is one of the most satisfactory text-books in our language on the topic of which it treats, as the fundamental principles are developed at length, and practical examples illustrating various applications of the method are given in sufficient number. The first 174 pages of the new edition are identical with the corresponding part of the old. A new chapter has been inserted, on the solution of normal equations; also four pages of notes have been added, explanatory of difficulties in certain parts of the old edition.

Rice: The Theory and Practice of Interpolation; The Nichols Press; pp. 234.

The author is an assistant in the office of the American Ephemeris, and has "felt the need of a book that would give, exclusive of other matter, a simple, practical and yet comprehensive discussion of all that is useful concerning differences, interpolation, tabular differentiation and mechanical quadrature." The author has not only felt this need, but has been able to supply it in a most satisfactory manner, having produced a thoroughly practical and usable book, which will please at once the student, and the practical computer.

Hayford: A Text Book of Geodetic Astronomy; John Wiley & Son, publishers; pp. 351; $3.00.

Mr. Hayford is connected with the U. S. Coast Survey and has written this text book to prepare engineering students for post-graduate practice in geodetic work. A single college term he deems sufficient for this. The introductory chapter gives those fundamental astronomical notions which are needed; the next chapter shows how to compute the apparent places of celestial objects. The five following chapters deal with the sextant, the astronomical transit, the zenith telescope, and the therdolite, explaining fully how to get latitude, longitude and azimuth with them. At the end of almost every chapter are questions and examples. The last chapter gives suggestions about observing and computing, and is followed by over sixty pages of tables, formulæ, etc. The book seems well adapted to its purpose.

ARE THERE POSSIBLE MARTIANS?

G. SENECA JONES.

For Popular Astronomy.

An article entitled "What we know about Mars," written by Professor Edward S. Holden and published in the March number

of *McClure's Magazine*, doubtless has been widely read and probably has been accepted generally as an exposition of the views regarding the planet now held by astronomers of high standing, and, therefore, as a timely check on the mass of very sensational Martian literature which has flowed in abundance from less responsible sources.

The question now uppermost in the public mind with regard to the planet Mars is whether or not it is fitted for sustaining human life. It is from this point of view that Professor Holden treats his subject. He reaches the conclusion that the planet is uninhabited and uninhabitable for two excellent reasons, if for no others; first, because the temperature of Mars is so low that a terrestrial man, could he miraculously be transported thither, "would undoubtedly freeze solid in an exceedingly short time;" and, second, for the equally good reason that "at any rate there is not sufficient air [on the planet] to sustain human life."

These views regarding Mars may or may not now be held by the majority of those astronomers who have given to the question of its habitability any especial thought. We are inclined to think, however, that very few astronomers would risk opinions on these points so decided as those which the writer of this article has put forth. It is to be regretted, therefore, that in support of his convictions he has chosen to confine his attention to two or three points, and, with unpardonable injustice to the readers whom he has undertaken to enlighten on the present aspect of the case of Mars, has neglected to state the most significant of the facts now known which bear on the planet's capability of sustaining life. Moreover, there are statements in the article, made most positively, which certainly will not be endorsed as beyond question by astronomers generally. It may not be amiss, therefore, in the interest of the general reading public, to examine some of these statements, and to supply some of the omissions.

After enumerating the sources of several popular errors regarding Mars, the writer comes to the question of the "polar caps," and explains how it was that Sir William Herschel became confirmed in the opinion, already held by astronomers, that these caps were deposits of snow. Herschel observed that they varied in size with the changes of the Martian seasons, being the largest in winter and nearly or quite disappearing in summer. He supposed them to melt and become water. At this point we come upon one of the statements referred to above, which is as follows:

"The explanation was correct, so far as his knowledge then

went. We now know two facts that make it impossible. In the first place, according to the best knowledge attainable, the temperature of Mars is *always* far below the freezing point. Water can never melt on Mars. In the second place there is, in fact, little or no water on Mars. The observations at the Lick Observatory have shown this conclusively and this result is now generally accepted.

"The 'polar caps' exist, however. What are they? The answer is that it is not (yet) certainly known. It is very likely that they may be composed of carbon dioxide. This vaporizes (and becomes invisible) at — 109° of Fahrenheit's thermometer. At a lower temperature than that it is deposited as a white 'snow.' A layer an inch thick (or less) would account for all the observed phenomena. This explanation may not be correct, but it is worthy of serious examination. Whether it is correct or not it is certain that the polar caps of Mars are not composed of 'snow'. Snow is water, and there is no water to speak of on the planet. Moreover the polar caps 'melt,' and the temperature of the Arctic regions of Mars is always below the melting temperature of water. The polar caps of Mars are not 'snow'."

These several assertions could not have been made more confidently had the writer actually been upon Mars and decided the matter by a personal inspection. Naturally the reader will be curious to know the precise nature of this "best knowledge attainable" upon which are based conclusions of such importance. The suggestion that the polar caps of Mars may be carbon dioxide is not new. It is based upon a single fact only, namely, that at the distance of Mars from the Sun the solar radiation both of light and heat has less than one-half—about four-ninths—of the intensity which it has at the distance of the Earth. This is the only ground—for the spectroscope is powerless to decide the matter—upon which some astronomers have been led to doubt that these caps are snow, as has been held in the past most probably to be the case and as is still the prevalent view of them.* Upon this point Professor Young is quoted by the writer as saying, with a reference to the diminished

* It may be that Professor Holden also had in mind an opinion recently put forth by Dr. G. Johnston Stoney, based on the kinetic theory of gases, that, owing to its low gravitational power, Mars has lost all of the lighter elements of its atmosphere, including its water in the form of vapor, and that the polar caps are probably carbon dioxide. Dr. Stoney's theory of planetary atmospheres, satisfactory as it has seemed to be in the case of the Moon, has recently been given a severe blow by the demonstration of the fact, by Professors Liveing and Dewar, that the Earth's atmosphere contains both hydrogen and helium in appreciable quantities. A theory which is itself still on trial cannot be permitted to outweigh the testimony of observed facts.

power of the solar radiation above noted, "The inference is almost irresistible that the temperature [of Mars] must be appallingly low—so low that water, if it exists at all, can exist only in the form of ice." Professor Newcomb is also quoted as saying that it is by no means certain that the polar ice-caps are ice at all.

Ten years ago and even less the obstacle here noted was really a very serious one in the way of those who held that Mars might be habitable. It did seem that the temperature on the planet ought to be excessively low, and there was no satisfactory way of meeting the difficulty. There are now, however, at least two lines of reasoning along which we may approach the question of the Martian temperature, one based upon a recent discovery in radiant heat, which greatly lessens the improbability of the existence of water in the liquid form upon Mars; the other is the seasonal recurrence upon Mars of certain remarkable phenomena which can be accounted for satisfactorily only on the supposition that the polar caps are snow—or hoar frost, as now seems more probable—with all the consequences which that supposition carries with it.

The inference that the temperature of Mars must be "appallingly low," as compared with the Earth's, involves the assumption that the Sun's effective heating power at the distances of the several planets is diminished in the same ratio as the strength of its radiation is diminished, that is, as the square of the distance is increased. There is now reason to believe that this assumption is incorrect. A law of heat radiation, known as "Stefan's Law," formulated from the theory some twenty years ago, has been subjected to experimental tests within the last four or five years, by Paschen and other scientists, and has been found to be valid, at least within the limits of 100 degrees of temperature on the absolute scale—173 degrees below zero centigrade—and 1700 degrees absolute. The law is that the effective radiation from a "perfect radiator," such as the Sun is assumed to be, is proportional, not to the temperature of the radiating body, but to the fourth power of that temperature. A body heated by radiation becomes itself a radiator, its temperature rising until its radiation—the heat which throws it off—exactly equals in amount that which it receives. This enables us to institute a comparison by means of the law just given, between the Sun's heating power on the Earth and on Mars, in the following way: Suppose, to make a case as simple as possible, two tiny bodies which are perfectly black and therefore are "perfect radiators," to be situated,

one in the Earth's orbit, the other in that of Mars. Each is heated by the Sun until its radiation equals the solar radiation at its distance from the Sun. Call the temperature of the inner of these two bodies T; that of the outer, T_1. According to the law above enunciated, the fourth powers of T and T_1 are proportional to the radiations of the inner and outer body respectively. We know that the radiation of the outer body is four-ninths that of the inner, and we easily figure out that the temperature of the outer body is 0″.82 that of the inner, this decimal being the fourth root (very nearly) of the fraction four-ninths. That is to say, the Sun's effective heating power at the distance of Mars, instead of being less than half, as heretofore supposed, is about 82 per cent of its heating power at the distance of the Earth. A permanent diminution to the extent of eighteen per cent in the annual supply of solar heat would doubtless cause great climatic changes on the Earth; but it may be doubted if it would result in a total destruction of terrestrial life and the permanent freezing of the Earth's water.

The second line of argument above referred to can be the best presented in connection with the story of Martian observations within the last eighty years. On August 4, 1892, occurred one of the most favorable oppositions of Mars, so far as concerns distance from the Earth; but, unfortunately, the planet "ran low" for observers in the northern hemisphere, being in that part of the heavens traversed by the Sun in midwinter. Professor Holden was then the director of the Lick Observatory. In an article published in *Astronomy and Astro-Physics* for October, 1892, "Note on the Mt. Hamilton Observations of Mars," he says:

"Although the situation of Mars in this opposition is very unfavorable, it was desirable to obtain as many observations as possible. The altitude of the planet ranges from about 28 degrees to about 32 degrees above the horizon, which is too low for satisfactory images of so difficult an object, even at Mt. Hamilton." In spite of the unfavorable conditions, however, the astronomers there did much very excellent work during the summer, as is shown by the closeness with which the published sketches of the planet made by the several observers agree with one another and with drawings made two years later under better conditions at Mr. Percival Lowell's Observatory at Flagstaff, Arizona.

Among the things noted by the Mt. Hamilton observers on this occasion were certain surprising changes in the general aspect of

the planet. Professor Holden, in the paper just cited, speaks of them as follows:

"It is not practicable to describe the remarkable changes that have been noted on the surface of the planet without a set of copies of the drawings for reference. There have been very many such. Marked changes have occurred in certain regions during the present opposition (notably in the polar cap, the region north and east of Lacus Solis, in the Fons Juventae, etc.). In many cases a feature has remained tolerably constant during the whole opposition, but is markedly different in its present form or color from the representations made in former years. . . . In some instances we have change of form alone; in others change of color; in a few cases the changes of form and color seem to be associated."

In conclusion he says: "I may briefly state my individual conclusions, as derived from a comparison of my own observations of Mars at the opposition of 1875 and all succeeding ones, to be that the changes in the surface features of Mars as we now know them are probably not capable of being completely explained by terrestrial analogies. What are we to make of the lake called Fons Juventæ, for example, which was a single object in 1877, which was not visible in 1879, and which has been both single and double during the present year? The dark areas on Mars may be water and the red areas land; but how are we to explain the faintly colored areas like Hesperia or Deucalionis Regio? Are they vast shoals like the Grand Banks of Newfoundland? Are they solid land, or are they water? Is it conceivable that an observer on Mars, examining the Earth in any part of its recent history, would have seen any such amazing topographic changes as we have this year observed, not to speak of the changes from opposition to opposition?"

Strange to say, in the magazine article now before us, written for the information of the general public, and claiming through its title to present the existing state of our knowledge respecting Mars, the "amazing changes" observed at Mt. Hamilton and elsewhere to occur upon the planet in 1892, and which have been repeated and observed at every subsequent opposition, are passed in absolute silence. It would be interesting to know how Professor Holden accounts for these striking evidences of activity of some sort on the surface of a planet where "it is certain" that everything is perennially frozen solid.

Similar, though less extensive changes had been observed before by Schiaparelli and others, and upon the assumption that what-

ever upon Mars had a greyish or greenish color was a body of water, they were supposed to be due to inundations caused by the liberation of a vast volume of water through the melting of the polar snows.

The true solution of this Martian enigma—the most important of the discoveries which have lately been made respecting Mars (a discovery which the Mt. Hamilton observers failed to make because of the poor "seeing" in 1892)—was found during this same opposition by the more favorably situated astronomers at the Harvard College Branch Observatory at Arequipa, in Peru. This Observatory is situated at an altitude above the sea nearly twice as great as that of the Lick Observatory, in an atmosphere which for purity and steadiness is probably unsurpassed, if it is equaled, at any other astronomical station in the world. More than this, at the opposition of 1892 the planet Mars crossed the meridian at Arequipa very nearly in the zenith. Under these circumstances Professor W. H. Pickering, the astronomer in charge of the Observatory, and his assistant, Mr. A. E. Douglass, though using a telescope of only 13 inches aperture, had probably the finest views of Mars which down to that time had fallen to the lot of any astronomer. What they saw and what they conjectured, may be gathered from the following extracts from an article written by Professor Pickering, dated Arequipa, August 1, 1892, and published in the same number of *Astronomy and Astro-Physics* that contains the Mt. Hamilton report, above cited:

"The changes which have occurred [on the surface of the planet] at the present opposition have been so conspicuous and startling that they might easily be detected even by the possessors of six-inch telescopes. The canals can now be observed readily on any evening. Many of those that we have seen here agree with Schiaparelli's and several do not. . . . Some very well developed canals cross the oceans. If these are really water canals and water oceans, there would seem to be some incongruity here. When the snow melts, it seems that there really should be some oceans, and a careful study has been made of the dark spot previously referred to, at the northern end of the Syrtis Major. Although sometimes dark gray, yet in the great majority of cases when the seeing is satisfactory, and the spot is central, it appears of a clearly defined dark blue color. Another spot presenting a precisely similar appearance occupies a portion of the Sinus Sabaes or Herschel Strait. . . . It is my impression that these two areas are really water. . . As I have stated in

former articles, I very much doubt if what are usually known as oceans and canals contain any water at all. This is to say, any water which is visible as such, for it is possible and perhaps probable that they may owe this color indirectly to the presence of water."

In previous communications to the same periodical Professor Pickering had given an account of a study of the colors exhibited by the disc of Mars, which he had begun at the Harvard College Observatory, in 1890, and had continued at Arequipa, in the spring of 1892. He had found the investigation not a simple one. The effect of the atmosphere, particularly when the "seeing" was poor, often misled the judgment. Greens, for example, were apt to appear as grays. He had convinced himself, however, that certain areas of the planet had really a green color which could not be accounted for either by poor seeing or as effects of contrast. In a paper dated at Arequipa, May 13, 1892 he speaks of certain color changes which had already been observed as follows:

When the Syrtis Major is central, before the autumnal equinox of the northern hemisphere, the region to the east is seen to be distinctly more greenish than that to the west. As the season wears on the difference becomes less marked, and the greenish hue is confined more closely to the region immediately bordering the Syrtis on the east. . . . Early in 1890 the entire region enclosed between the arms of the Syrtis Major, as far as the snow cap, was of a brilliant green color. On June 27, however, or eleven days before the vernal equinox of the southern hemisphere, a yellow spot appeared at the extreme northern point of the triangular area. As the season advanced, this yellow spot increased in extent, till it covered the whole area as far south as could be seen. This year when first observed this area was entirely green, but on May 9, or seventeen days before the vernal equinox the yellow, or perhaps reddish spot appeared in the same place, and it will be interesting to determine if, as the season advances, this color again progresses towards the pole." Two other large greenish areas are also mentioned as having undergone similar changes of color.

As to the significance of these color changes Professor Pickering refrained in this paper from expressing any opinion. In his next communication, written two months and a half later—the first above cited—after the changes had been observed to come "so thick and fast upon the planet" that when evening came around and the two observers put their eyes to the telescope "we

never knew what we should see next," he is equally guarded in making any surmise as to their causes. The following passage, however, shows plainly the thought which he had in mind and indicates that really he had come to a decision in the matter: "While their reappearance"—that of certain green areas of which he has been speaking—"might with some show of probability be attributed to the presence of one of the great branches of organic life upon the planet, and with this branch, as an almost necessary corollary, the other one, we must still consider the matter merely in the light of a tentative hypothesis, until further observations are accumulated, and content ourselves with the statement that no facts have as yet been observed inimcal to this idea."

Observations have since accumulated—notably the splendid series made by Mr. Percival Lowell and his assistants at Flagstaff, in 1894 and subsequently—and the statement still holds good that no facts have been observed inimical to the idea that these color changes upon Mars, which have been found to repeat themselves at corresponding seasons of the Martian year, are due, in part at least, to the growth and decay of vegetation. It is now certain that there are no large bodies of water upon Mars. Convincing evidence of this is afforded by the observed fact that many of the "canals" traverse the dark areas formerly supposed to be seas. Some of the smaller and more deeply colored of the dark areas which make their appearance simultaneously with the melting of the polar caps may well be due to an increase in the size of lakes too small to be ordinarily visible, or to the formation of temporary lakes by the liberated water; but for the larger portion of the color changes observed the inundation theory does not afford a satisfactory explanation of all observed facts, while the vegetation theory does account for them admirably. The changes are, indeed, just such as a supposable lunar astronomer might observe taking place over the Earth's temperate zones, were he to keep a watch upon the Earth for an entire year.

The permanently dark areas upon Mars, then—areas formerly supposed to be oceans—and those which are variable in color must be regarded, in the light of these recent observations, as probably the planet's lowlands, where, if anywhere, are to be found its forests and meadow lands, while its orange colored areas—its "continents"—are probably regions of a higher elevation, which, in all likelihood, because of the rainless condition of Mars, are arid deserts.

If we accept this evidence that Mars has vegetation, have we any grounds upon which we can base a reasonable conjecture as to the character of the vegetation? Upon this point it may be said that the range of speculation regarding life in the other worlds than ours has been greatly restricted by the progress of the natural sciences in the last few years, and even more by the discoveries made with the spectroscope. It is now known, on the testimony of this instrument, that the material of which worlds are made is everywhere throughout the visible universe the same. It may confidently be assumed that the properties of matter are also everywhere the same. We must conclude, therefore, that chemistry—inorganic, at least—is everywhere the same, just as we believe that the law of gravitation is of universal application. Organic chemistry admits, no doubt, of more latitude of speculation, owing to the greater variety of forms to which it may give rise; but that its principles are everywhere essentially the same, we must believe, and we may reasonably conjecture that it yields everywhere essentially the same results, and that our terrestrial types of life are universal types. The time is past when it might be reasonably conjectured that there are worlds in which silicon takes the place of lime in the formation of bone, or worlds in which a slight change of composition renders chlorofol red instead of green, or that life, whether vegetable or animal, is possible any where at the temperature of boiling water. While we may not be warranted in concluding from these premises that the Martian flora and fauna present the same series of species and genera as the terestrial, or substantially the same, still this is by no means unlikely. We know, at any rate, that the Martian vegetation is green, like the Earth's, not red, as has been held to be possible, and this is one point scored.

But whatever views may be held upon the points above raised, no naturalist will now hazard the surmise seriously that life is anywhere possible under conditions which would render it impossible upon the Earth—that, for instance, life of any kind could exist upon Mars were the temperature there permanently below the freezing point of water. This should decide the question of the nature of the polar caps. Water, in the form of snow or frost, is the only substance to which they can be referred until we come to a temperature 109 degrees below zero Fahrenheit, and a degree of cold so intense as this, even locally and temporarily, upon a planet capable of sustaining life is hardly supposable.

Having decided that the Martian polar caps are in all proba-

bility really snow caps, we are next led to a conclusion which is somewhat of a surprise, considering the point at which we started, namely, that the average temperature upon Mars, instead of being lower, is really higher than upon the Earth. This is indicated by the fact that the polar caps never reach to so low a latitude as do the Earth's winter snows—about 65 degrees of Martian latitude is the lowest line to which the southern cap has been observed to descend—and that in summer they nearly and sometimes entirely melt away. It is needless to say that this never happens to the Earth's polar caps; and yet, since the axis of Mars and that of the Earth have about the same inclination to the ecliptic, the obliquity of the Sun's rays in different latitudes at different seasons is practically the same for each planet. The complete explanation of the higher Martian temperature thus plainly indicated by these natural thermometers, doubtless, like that of all other meteorological phenomena, is a complex one. One factor which certainly enters largely into the solution of the problem is the fact that there are no extensive oceans upon Mars as there are upon the Earth, to absorb a large portion of the Sun's radiation without becoming greatly heated thereby, and that the whole power of the solar heat rays is employed in heating a land surface—a surface, too, of which the larger portion is, apparently, unprotected by vegetation; is a sort of Sahara desert. How this circumstance alone affects the annual average temperature of the whole planet, it may be hard to say. Its effect in the summer season of either hemisphere may easily be a temperature considerably higher than the average summer temperature upon the Earth, in spite of the fact that the heating power of the Sun is less there than here. Why the winters are not correspondingly cold, is not so obvious.

A few words in conclusion about the atmosphere of Mars. There can be no question that there is upon this planet an atmosphere of some kind, although both theory and observation lead to the conclusion that it is very much less dense than the Earth's. Very likely it is, as Professor Holden assures us, "less in amount than that surrounding the summits of the highest Himalayan peaks." As to the composition of this air, the presumption—in view of what we know of the materials of which worlds are made—is that it is essentially the same as the Earth's. We know, at any rate, that it contains carbon dioxide, else there could be no vegetation upon Mars, and, by the same token, we know that it also contains oxygen, and it must also contain aqueous vapor, for without this there could be no snows or

frosts upon the planet. Whether or not it also contains nitrogen and in what proportions its various constituents are mixed, it is impossible to say. Still, in view of what we do know in the matter, the uncertainty in these respects is hardly great enough to warrant the declaration that "It is more than likely that what air there may be upon Mars is of a kind fatal to human life." On the contrary, we would throw the likelihood into the other scale of the balance. Nor is the excessive tenuity, of the Martian atmosphere so serious a matter, perhaps, as Professor Holden would have us think. At any rate, we know that here upon the Earth the range of atmospheric density within which human beings may exist without discomfort is quite large. Workmen engaged upon submarine structures may be enclosed for hours at a time in caissons in which the air is compressed to a density two or more times that which they ordinarily breathe. On the other hand, mountain climbers are not badly oppressed for breath at the height of the summit of Mt. Blanc, where the atmosphere has barely more than one-half its density at the sea level, and aeronauts have never been seriously affected by the rarity of the atmosphere until they have reached an altitude of over five miles—have ascended nearly or quite to the height of the highest peaks of the Himalayas. In view of facts such as these it seems probable that if the Earth's atmosphere should slowly decrease in density through successive centuries, the existing lung-breathing terrestrial animals, man included, would become adapted to the changed condition, and that the atmosphere might attain to a state of rarity much greater even than that of the air of Mars, before it would become insufficient in amount to sustain human life, even as we are now constituted.

A discussion of the "canals" of Mars does not fall within the scope of the present article, the purpose of which has been to present fairly and as completely as possible within the reasonable limits of such an article the present state of the evidence that Mars, far from being a frozen-up world, of which the "nearest analogue in the solar system is our own Moon," is a habitable world. The evidence that it has vegetation of some sort, that comes and goes, like the Earth's with its change of seasons, is as nearly conclusive as such evidence can well be. If the planet has vegetation, we can hardly doubt that it has animal life also.

Professor E. C. Pickering of Harvard College Observatory has received the Gold Medal of the Royal Astronomical Society, awarded for researches on Variable Stars, and his work in Astronomical Photography. A most able address was delivered by the President, Mr. E. B. Knobel, accompanying the award. The address is published in the *Monthly Notices* of the Society.

ESTABLISHING A MERIDIAN LINE.

GEORGE C. COMSTOCK.

FOR POPULAR ASTRONOMY.

In connection with the teaching of elementary astronomy I have recently had to consider the problem of marking out upon the ground a meridian line without the aid of any astronomical tables, instruments or other appliances beyond what may be readily improvised from the resources of an ordinary school room or home and the following brief résumé of the results obtained may be of interest to others.

Assuming that under the circumstances here considered it will always be feasable to construct a plumb line five or six feet long which can be suspended with its weight swinging in a bucket of water to check vibrations, one may by sighting past it "plumb down" from Polaris, set two stakes on line with the star and note from a watch the time at which this is done. The line thus determined will be nearly in the meridian and will require only a small shifting of one of the stakes toward the east or west to furnish the true meridian. The amount of this offset must be determined from the recorded time at which the observations were made and for this purpose the error of the watch *referred to local time* must be determined by comparing it with railway time and correcting for the difference of longitude between the observer's local meridian and the standard meridian. Scale off this difference of longitude from some map and also read off the latitude of the place of observation as this will be required in the subsequent reduction.

The next step is to determine the hour angle of the star at the time it was observed and for this purpose we note that Polaris and the mean sun are in conjunction on April 12, and on that date the hour angle of the star at any moment is equal to the time shown by the watch; *e. g.* at 7 P. M. the star's hour angle is $7^h = 105°$. Owing to the eastward motion of the mean sun in right ascension, at the rate of nearly four minutes of time per day, the hour angle of Polaris on subsequent days will be greater than the time shown by the watch but may be found upon any date from the equation

$$t = W + 4\,(\text{Date} - \text{April } 12)\left[1 - \frac{1}{70}\right]$$

where W denotes the local mean solar time; the interval Date — April 12 is to be expressed in days and the product of the three

factors composing the last term is given in minutes of time. The co-efficient, 4, when multiplied by the factor $1 - \frac{1}{70}$ gives the daily motion of the mean sun in minutes of time. The date of conjunction, April 12, is not quite the same in all years on account of the star's precession but comes about a day later at the end of each decade, April 13 in 1910, April 14 in 1920, etc.

The hour angle, t, as given by this equation may be anything from 0^h to 24^h and in place of it we now substitute the hour angle reckoned either forward or backward from the nearest culmination, either above or below the pole, *i. e.* we take

$$\tau = t, \text{ or } = 12^h - t, \text{ or } = t - 12^h, \text{ or } = 24^h - t,$$

use whichever one of these relations will make τ less than 90° and find from it the star's true azimuth at the time of observation through the following simple construction, Fig. 1.

At one end of a straight line, p, whose length is taken to represent the polar distance of Polaris, construct an angle equal to τ and at the other end construct an angle equal to the sum of the latitude, ϕ, and the complement of τ *i. e.*, $90° - \tau + \phi$. Produce the sides of these angles until they meet and in the resulting plane triangle the side, a, opposite to the angle τ will represent the azimuth of Polaris upon the same scale that the side p represents the polar distance. For this construction the polar distance of the star may be assumed to be 1.23° at the epoch 1900 and to diminish 0.01° for each two years thereafter, *i. e.*,

$$p = 1.23° - 0.005° \, (T - 1900)$$

If p is given in degrees a will of course be read from the diagram in degrees and its application to determining the offset to be made from the stakes driven at the time of observation, will be greatly facilitated if these stakes were set 47 feet 9 inches apart. In this case lay off ten inches for every degree contained in a and note that the northern stake is to be moved toward the east if the hour angle, t, was less than 12^h but must be moved toward the west if t was greater than 12^h.

To show that the construction given above correctly represents the azimuth of the star we assume the development of this azimuth, A, reckoned from the north, in a series proceeding according to the powers of the polar distance, as follows, where only the first two terms of the series are given:

$$A = p \sec \phi \sin t + \frac{1}{2} p^2 \sec \phi \tan \phi \sin 2t + \ldots\ldots$$

In Fig. 1 the broken line is a perpendicular let fall upon one side

of the triangle and from the geometrical relations involved it is easy to see that this line divides the angle $90° - \tau + \phi$ into the two parts, $90° - \tau$ adjacent to p and ϕ adjacent to a. From the figure the length of the broken line is either $p \sin \tau$ or $a \cos \phi$ and from the resulting equality of these two expressions we have

$$a = p \sec \phi \sin \tau = \pm p \sec \phi \sin t$$

i. e. a is the first term in the complete expression for the azimuth and the second term in the expression above given for A measures the error of the azimuth read from the diagram, which is thus seen to be only approximately correct. In latitude 60° the maximum value of this error does not exceed 3′ which is but little if at all greater than the probable error of the observations, while within the limits of the United States the error involved in the construction will rarely surpass 2′.

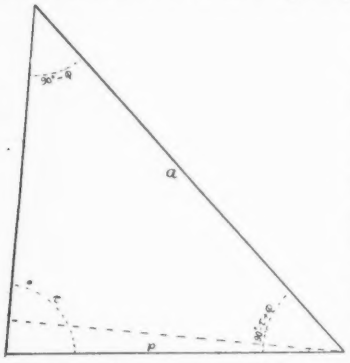


FIG. 1. AZIMUTH OF POLARIS.

Errors in the observed time or in the assumed latitude will also affect the precision of the resulting meridian line but only to a minor degree and under ordinary circumstances an error of five minutes in the time or a degree in the latitude represents the limit below which errors of this kind are of little consequence. Errors of even less consequence than the foregoing are those arising from the nutation, aberration and the disturbing effect of the bissextile day in leap years, all of which are ignored.

Fig. 1, which is accurately drawn to scale, represents an observation of Polaris, such as is described above, made at Madison, Wis., March 10, 1901, at 7:45 P. M., Central Standard Time. From the map consulted, Madison appears to be in latitude 43.1° and to be half a degree (2m) east of the 90th meridian. With this data we readily obtain

$$t = \tau = 5^h\ 37^m = 84.2° \qquad 90° - \tau + \phi = 48.9°$$

and the triangle was constructed with these angles, laid off by means of a protractor, and with an assumed $p = 1.23°$. The azimuth scaled off from the diagram is $a = 1.68°$, while from a trigonometrical computation, based upon the data of the *American Ephemeris*, I find for the given time and place $A = 1.66°$ west of north.

In connection with the allied problem of determining the latitude from an observed altitude of Polaris we may note that the distance from the vertex of the angle τ to the foot of the broken line shown in Fig. 1, represents the difference between the star's altitude and the latitude and may therefore be applied as a correction by which to pass from one to the other, the degree of approximation being practically the same as in the case of the azimuth, a. Thus from Fig. 1 we may obtain by direct measurement $h - \phi = 0.12°$, the altitude being greater than the latitude since t is less than 6^h. The true difference, $h - \phi$, derived from a trigonometric computation, was 0.11°.

GENERAL PERTURBATIONS AND THE PERTURBATIVE FUNCTION.*

J. MORRISON, M. A., M. D., PH. D.

FOR POPULAR ASTRONOMY.

From (3) we see that Θ is a function of the masses of the planets (m) and (m') and of the distance between them, and from (4) that it possesses the property of representing by its partial derivatives, the action of the planet (m') on (m). The whole theory of perturbations rests on the consideration of this particular function which can be developed into an infinite series of terms of the form

$$m'A \cos (int - i'n't + B)$$

where nt and $n't$ represent the mean motions of the disturbed and disturbing planet; i and i' whole numbers which can have all possible values, positive or negative including zero, and A and B functions of the elements of the orbits but independent of the time t.

In order to simplify the development of this function as much as practicable we shall consider only the reciprocal action of two planets (m) and (m') in their motion around the Sun.

Equation (3) is

$$\Theta = \frac{m'}{1+m}\left(\frac{1}{\rho} - \frac{xx' + yy' + zz'}{r'^3}\right)$$

$$= \frac{m'}{1+m}\left(\frac{1}{\rho} - \frac{r^2 + r'^2 - \rho^2}{2r'^3}\right), \text{ by (1)}$$

If δ denote the angle formed at the centre of gravity of the Sun by the two radii vectores r and r', we shall have

* Continued from Volume IX, page 145 of POPULAR ASTRONOMY.

$$\rho^2 = r^2 + r'^2 - 2rr' \cos \delta$$

and if v and v' represent the longitudes of the planets (m) and (m'), τ and τ' the longitudes of their common node, reckoned on the plane of their orbits and from a fixed axis, and γ the mutual inclination of their orbits, then from the spherical triangle whose two sides are $v - \tau$ and $v' - \tau'$ and the included angle γ, we have

$$\begin{aligned}\cos \delta &= \cos (v - \tau) \cos (v' - \tau') + \sin (v - \tau) \sin (v' - \tau') \cos \gamma \\ &= \cos (v - v' - \tau + \tau') - 2 \sin (v - \tau) \sin (v' - \tau') \sin^2 \frac{\gamma}{2} \\ &= \cos (v - v' - \tau + \tau') + \cos (v + v' - \tau - \tau') \sin^2 \frac{\gamma}{2} \\ &\qquad - \cos (v - v' - \tau + \tau') \sin^2 \frac{\gamma}{2}\end{aligned}$$

But since the factor $\sin^2 \frac{\gamma}{2}$ is always very small, we can without appreciable error, put $\tau = \tau'$ and writing η^2 for $\sin^2 \frac{\gamma}{2}$ the above becomes

$$\cos \delta = \cos (v - v') + \eta^2 \{\cos (v + v' - 2\tau) - \cos (v - v')\}$$

which substituted in the value of ρ^2 gives

$$\rho^2 = r^2 + r'^2 - 2rr' \cos (v - v') - 2rr'\eta^2 \{\cos (v + v' - 2\tau) - \cos (v - v')\}$$

and this substituted in the value of Θ gives

$$\Theta = \frac{m'}{1 + m} \left\{ \left(r^2 + r'^2 - 2rr' \cos (v - v') - 2rr'\eta^2 [\cos (v + v' - 2\tau) - \cos (v - v')] \right)^{-\frac{1}{2}} - \frac{r}{r'^2} \left(\cos (v - v') + \eta^2 [\cos (v + v' - 2\tau) - \cos (v - v')] \right) \right\} \quad (55)$$

For brevity put

$$2\zeta = \cos (v + v' - 2\tau) - \cos (v - v')$$

and

$$Q = r^2 + r'^2 - 2rr' \cos (v - v'); \quad (56)$$

then the above becomes

$$\Theta = \frac{m'}{1 + m} \left\{ (Q - 4rr'\eta^2\zeta)^{-\frac{1}{2}} - \frac{r}{r'^2} \cos (v - v') - \frac{2rr'}{r'^3} \eta^2 \zeta \right\}$$

$$= \frac{m'}{1+m}\left\{Q^{-\frac{1}{2}} - \frac{rr'}{r'^3}\cos(v-v')\right\}$$
$$+ \frac{m'}{1+m}\left\{2rr'\eta^2\zeta\left(Q^{-\frac{3}{2}} - \frac{1}{r'^3}\right)\right\} \qquad (57)$$
$$+ \frac{m'}{1+m}\left\{6r^2r'^2\eta^4\zeta^2 Q^{-\frac{5}{2}}\right\}$$
$$+ \frac{m'}{1+m}\left\{20r^3r'^3\eta^6\zeta^3 Q^{-\frac{7}{2}}\right\}$$
$$+ \ldots\ldots \quad \ldots\ldots\ldots\ldots$$

By neglecting for the present the terms containing η^2, which are very small, we see that Θ depends on r, r', v and v'. The angle γ which enters implicitly into the last three terms of (57) is itself a function of the inclinations of the orbits to the plane of xy, and of the longitudes of the ascending nodes; for in the spherical triangle whose side is $\Omega - \Omega'$ and adjacent angles i and $180° - i'$ we have for computing the angle γ opposite to this side

$$\cos\gamma = \cos i\cos i' + \sin i\sin i'\cos(\Omega - \Omega') \qquad (58)$$

In order to develop the terms of (57) into a series proceeding according to powers of the eccentricities, we put

$$\begin{aligned} r &= a + a\lambda \\ r' &= a' + a'\lambda' \\ v &= l + \nu \\ v' &= l' + \nu' \end{aligned} \qquad (59)$$

where λ, λ', ν and ν' are very small quantities depending on the eccentricities of the orbits of (m) and (m') and l and l' the mean longitudes $nt + \epsilon$ and $n't + \epsilon'$ of the planets respectively. Substituting these values of r, r', v and v' in (57) and neglecting at first λ, λ', ν and ν' and denoting by Θ_0 what Θ becomes under this condition which is that of circular orbits, we have

$$\Theta_0 = \frac{m'}{1+m}\left\{Q_0^{-\frac{1}{2}} - \frac{a}{a'^2}\cos(l-l')\right\}$$
$$+ \frac{m'}{1+m}\left\{2aa'\eta^2\zeta_0\left(Q_0^{-\frac{3}{2}} - \frac{1}{a'^3}\right)\right\} \qquad (60)$$
$$+ \frac{m'}{1+m}\left\{6a^2a'^2\eta^4\zeta_0^2 Q_0^{-\frac{5}{2}}\right\}$$
$$+ \ldots\ldots\ldots \quad \ldots\ldots\ldots\ldots$$

where $Q_0 = a^2 + a'^2 - 2aa'\cos(l-l')$

and $2\zeta_0 = \cos(l + l' - 2\tau) - \cos(l - l')$ (61)

We now pass to the case of eccentric orbits by attributing to a, a', l and l' the increments $a\lambda$, $a'\lambda'$, ν and ν'.

$$\text{Put} \quad Q_0^{-\frac{1}{2}} - \frac{a}{a'^2}\cos(l-l') = \frac{1}{2}\sum A^{(i)} \cos i(l-l'),$$

$$Q_0^{-\frac{3}{2}} - \frac{1}{a'^3} = \frac{1}{2}\sum B^{(i)} \cos i(l-l') \qquad (62)$$

$$\text{and} \quad Q_0^{-\frac{5}{2}} = \frac{1}{2}\sum C^{(i)} \cos i(l-l')$$

in which i has all integral values from $i = +\infty$ to $i = -\infty$ including 0 and the coefficients $A^{(i)}$, $B^{(i)}$ and $C^{(i)}$ are functions of a and a', and such that $A^{(i)} = A^{(-i)}$, $B^{(i)} = B^{(-i)}$ and $C^{(i)} = C^{(-i)}$. Making these substitutions in (60) and considering the first and second terms only, which are sufficient for our present purpose, it becomes

$$\begin{aligned}
\Theta_0 = & \quad \frac{m'}{1+m}\cdot\frac{1}{2}\sum A^{(i)} \cos i(l-l') \\
& - \frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa' \cos(l-l')\sum B^{(i)} \cos i(l-l') \\
& + \frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa' \cos(l+l'-2\tau)\sum B^{(i)} \cos i(l-l') \\
& - \quad \text{.....} \\
= & \quad \frac{m'}{1+m}\cdot\frac{1}{2}\sum A^{(i)} \cos i(l-l') \\
& - \frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa' \sum B^{(i-1)} \cos i(l-l') \qquad (63) \\
& + \frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa' \sum B^{(i-1)} \cos(i(l-l') + 2(l'-\tau)) \\
& - \quad \text{.....}
\end{aligned}$$

The transformations in the last two terms depend on the fact that the product of $\sum A^{(i)} \cos i\alpha$ for example, by the cosine of any other angle θ, is $\sum A^{(i)} \cos(i\alpha + \theta)$; thus, developing the expression $\sum A^{(i)} \cos i\alpha$ we have

$$\begin{aligned}
\sum A^{(i)} \cos i\alpha = A^0 + A^{(1)} \cos\alpha + A^{(2)} \cos 2\alpha + A^{(3)} \cos 3\alpha + \text{etc.} \\
+ A^{(-1)} \cos -\alpha + A^{(-2)} \cos -2\alpha \\
+ A^{(-3)} \cos -3\alpha + \text{etc.}
\end{aligned}$$

from which we see that the development proceeds in pairs of terms, and since $A^{(-i)} = A^{(i)}$ and $\cos -\alpha = \cos\alpha$, the above becomes

$$\sum A \quad \cos i\alpha = A^{(0)} + 2A^{(1)} \cos\alpha + 2A^{(2)} \cos 2\alpha + 2A^{(3)} \cos 3\alpha + \text{etc.}$$

now multiplying this by $\cos\theta$, we have

$$\begin{aligned}
\cos\theta \sum A^{(i)} \cos i\alpha &= A^0 \cos\theta + 2A^{(1)} \cos\alpha \cos\theta \\
&\quad + 2A^{(2)} \cos 2\alpha \cos\theta + 2A^{(3)} \cos 3\alpha \cos\theta + \text{etc.} \\
&= A^0 \cos\theta + A^{(1)} \cos(\alpha + \theta) + A^{(1)} \cos(\alpha - \theta) \\
&\quad + A^{(2)} \cos(2\alpha + \theta) + A^{(2)} \cos(2\alpha - \theta) \\
&\quad + A^{(3)} \cos(3\alpha + \theta) + A^{(3)} \cos(3\alpha - \theta) \\
&\quad + \quad \ldots\ldots\ldots\ldots \quad \ldots\ldots\ldots\ldots \\
&= A^{(0)} \cos\theta + A^{(1)} \cos(\alpha + \theta) \\
&\quad + A^{(2)} \cos(2\alpha + \theta) + A^{(3)} \cos(3\alpha + \theta) + \ldots\ldots \\
&\quad + A^{(-1)} \cos(-\alpha - \theta) \\
&\quad + A^{(-2)} \cos(-2\alpha - \theta) + A^{(-3)} \cos(-3\alpha - \theta) \\
&= \sum A^{(i)} \cos(i\alpha + \theta) \qquad (64)
\end{aligned}$$

In the same manner it is easily shown

$$\text{that} \quad \sin\theta \sum A^{(i)} \cos i\alpha = \sum A^{(i)} \sin(i\alpha + \theta)$$

$$\text{and} \quad \sin\theta \sum A^{(i)} \sin i\alpha = -\sum A^{(i)} \cos(i\alpha + \theta) \qquad (65)$$

Let us now consider the first term of (63) which is independent of η^2 or the inclination of the orbits to each other, and let us put

$$\Theta_{0,1} = \frac{m'}{1+m} \frac{1}{2} \sum A^{(i)} \cos i(l - l')$$

Now $A^{(i)}$ is a function of a and a' and therefore $\Theta_{0,1}$ is a function of a, a' and $(l - l')$, and when these variables receive the increments $a\lambda$, $a'\lambda'$ and $\nu - \nu'$ respectively we have by Taylor's Theorem

$$\begin{aligned}
\Theta_{0,1} = &\quad \frac{m'}{1+m} \cdot \frac{1}{2} \sum A^{(i)} \cos i(l - l') \\
&+ \frac{m'}{1+m} \cdot \frac{1}{2} \lambda \sum a \frac{dA^{(i)}}{da} \cos i(l - l') \\
&+ \frac{m'}{1+m} \cdot \frac{1}{2} \lambda' \sum a' \frac{dA^{(i)}}{da'} \cos i(l - l') \\
&- \frac{m'}{1+m} \cdot \frac{1}{2} (\nu - \nu') \sum i A^{(i)} \sin i(l - l')
\end{aligned}$$

$$
\begin{aligned}
&+\frac{m'}{1+m}\cdot\frac{1}{4}\lambda^2\sum a^2\frac{d^2A^{(i)}}{da^2}\cos i\,(l-l')\\
&+\frac{m'}{1+m}\cdot\frac{1}{4}\lambda'^2\sum a'^2\frac{d^2A^{(i)}}{da'^2}\cos i\,(l-l')\\
&-\frac{m'}{1+m}\cdot\frac{1}{4}(\nu-\nu')^2\sum i^2A^{(i)}\cos i\,(l-l')\\
&+\frac{m'}{1+m}\cdot\frac{1}{2}\lambda\lambda'\sum aa'\frac{d^2A^{(i)}}{da\,da'}\cos i\,(l-l')\\
&-\frac{m'}{1+m}\cdot\frac{1}{2}\lambda\,(\nu-\nu')\sum ia\frac{dA^{(i)}}{da}\sin i\,(l-l')\\
&-\frac{m'}{1+m}\cdot\frac{1}{2}\lambda'\,(\nu-\nu')\sum ia'\frac{dA^{(i)}}{da'}\sin i\,(l-l') \qquad (66)\\
&+\frac{m'}{1+m}\cdot\frac{1}{12}\lambda^3\sum a^3\frac{d^3A^{(i)}}{da^3}\cos i\,(l-l')\\
&+\frac{m'}{1+m}\cdot\frac{1}{12}\lambda'^3\sum a'^3\frac{d^3A^{(i)}}{da'^3}\cos i\,(l-l')\\
&+\frac{m'}{1+m}\cdot\frac{1}{12}(\nu-\nu')^3\sum i^3A^{(i)}\sin i\,(l-l')\\
&+\frac{m'}{1+m}\cdot\frac{1}{4}\lambda^2\lambda'\sum a^2a'\frac{d^3A^{(i)}}{da^2\,da'}\cos i\,(l-l')\\
&+\frac{m'}{1+m}\cdot\frac{1}{4}\lambda\lambda'^2\sum aa'^2\frac{d^3A^{(i)}}{da\,da'^2}\cos i\,(l-l')\\
&-\frac{m'}{1+m}\cdot\frac{1}{4}\lambda^2\,(\nu-\nu')\sum ia^2\frac{d^2A^{(i)}}{da^2}\sin i\,(l-l')\\
&-\frac{m'}{1+m}\cdot\frac{1}{4}\lambda'^2(\nu-\nu')\sum ia'^2\frac{d^2A^{(i)}}{da'^2}\sin i\,(l-l')\\
&-\frac{m'}{1+m}\cdot\frac{1}{4}\lambda\,(\nu-\nu')^2\sum i^2a\frac{dA^{(i)}}{da}\cos i\,(l-l')\\
&-\frac{m'}{1+m}\cdot\frac{1}{4}\lambda'\,(\nu-\nu')^2\sum i^2a'\frac{dA^{(i)}}{da'}\cos i\,(l-l')\\
&-\frac{m'}{1+m}\cdot\frac{1}{2}\lambda\lambda'\,(\nu-\nu')\sum iaa'\frac{d^2A^{(i)}}{da\,da'}\sin i\,(l-l')\\
&+\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots
\end{aligned}
$$

If we now substitute in this development the values of $\lambda, \lambda', \lambda^2, \lambda'^2$ ..... $\nu-\nu'$, $(\nu-\nu')^2$ ..... $\lambda\,(\nu-\nu')$, $\lambda'\,(\nu-\nu')$ ..... which are easily obtained from (39) and (40) we shall obtain the development of $\Theta_{0,1}$ proceeding according to the powers and products of the eccentricities, to any order of terms which we desire.

Terms which Depend on the First Power of the Eccentricities.

Let us first consider those terms which are independent of the eccentricities and those depending only on their first powers. From (39) and (40) we find

$$\begin{aligned} \nu &= a - ae\cos(l-\omega) \\ v &= nt + \epsilon + 2e\sin(l-\omega) \\ \nu' &= a' - a'e'\cos(l'-\omega') \\ v' &= n't + \epsilon' + 2e'\sin(l'-\omega') \end{aligned} \tag{67}$$

where we replace M by its values nt or $l-\omega$, n being the mean motion, l the mean longitude and ω the longitude of the perihelion, therefore we have

$$\begin{aligned} \lambda &= -e\cos(l-\omega) \\ \nu &= 2e\sin(l-\omega) \\ \lambda' &= -e'\cos(l'-\omega') \\ \nu' &= 2e'\sin(l'-\omega') \end{aligned} \tag{68}$$

Substituting these in the first four terms of (66) which are the only terms involving the first power of these increments, we have

$$\begin{aligned} \Theta_{0\cdot 1} = & \frac{m'}{1+m}\cdot\frac{1}{2}\sum A^{(i)}\cos i(l-l') \\ & -\frac{m'}{1+m}\cdot\frac{1}{2}e\cos(l-\omega)\sum a\frac{dA^{(i)}}{da}\cos i(l-l') \\ & -\frac{m'}{1+m}\cdot\frac{1}{2}e'\cos(l'-\omega')\sum a'\frac{dA^{(i)}}{da'}\cos i(l-l') \\ & -\frac{m'}{1+m}\cdot\frac{1}{2}2e\sin(l-\omega)\sum iA^{(i)}\sin i(l-l') \\ & +\frac{m'}{1+m}\cdot\frac{1}{2}2e'\sin(l'-\omega')\sum iA^{(i)}\sin i(l-l') \\ = & \frac{m'}{1+m}\cdot\frac{1}{2}\sum A^{(i)}\cos i(l-l') \\ & -\frac{m'}{1+m}\cdot\frac{1}{2}e\sum a\frac{dA^{(i)}}{da}\cos\Big(i(l-l')+l-\omega\Big) \\ & +\frac{m'}{1+m}\cdot\frac{1}{2}2e\sum iA^{(i)}\cos\Big(i(l-l')+l-\omega\Big) \\ & -\frac{m'}{1+m}\cdot\frac{1}{2}e'\sum a'\frac{dA^{(i)}}{da'}\cos\Big(i(l-l')+l'-\omega'\Big) \\ & -\frac{m'}{1+m}\cdot\frac{1}{2}2e'\sum iA^{(i)}\cos\Big(i(l-l')+l'-\omega'\Big) \\ = & \frac{m'}{1+m}\cdot\frac{1}{2}\sum A^{(i)}\cos i(l-l') \end{aligned} \tag{69}$$

$$-\frac{m'}{1+m}\cdot\frac{1}{2}e\sum\left\{a\frac{dA^{(i)}}{da}-2iA^{(i)}\right\}\cos\Big(i(l-l')+l-\omega\Big)$$

$$-\frac{m'}{1+m}\cdot\frac{1}{2}e'\sum\left\{a'\frac{dA^{(i)}}{da'}+2iA^{(i)}\right\}\cos\Big(i(l-l')+l'-\omega'\Big)$$

We may eliminate the partial derivative of $A^{(i)}$ with respect to a'; thus, since the coefficient $A^{(i)}$ is a homogeneous function of a and a' of -1 dimension, we have by Euler's Theorems of Homogeneous Functions

$$a\frac{dA^{(i)}}{da}+a'\frac{dA^{(i)}}{da'}=-A^{(i)}$$

whence

$$a'\frac{dA^{(i)}}{da'}=-A^{(i)}-a\frac{dA^{(i)}}{da} \qquad (70)$$

which substituted in the above gives

$$\begin{aligned}\Theta_{0\cdot1}=\quad&\frac{m'}{1+m}\cdot\frac{1}{2}\sum A^{(i)}\cos i\,(l-l')\\&-\frac{m'}{1+m}\cdot\frac{1}{2}e\sum\left\{a\frac{dA^{(i)}}{da}-2iA^{(i)}\right\}\cos\Big(i(l-l')+l-\omega\Big)\\&-\frac{m'}{1+m}\cdot\frac{1}{2}e'\sum\left\{(2i-1)\,A^{(i)}-a\frac{dA^{(i)}}{da}\right\} \qquad (71)\\&\qquad\cos\Big(i\,(l-l')+l'-\omega'\Big)\end{aligned}$$

Terms which depend on the Second Power of the Eccentricities.

From (39) and (40) we have as before

$$\begin{aligned}r&=a-ae\cos(l-\omega)+a\frac{e^2}{2}\Big(1-\cos 2\,(l-\omega)\Big)\\v&=nt+\epsilon+2e\sin(l-\omega)+\frac{5}{4}e^2\sin 2\,(l-\omega) \qquad (72)\\r'&=a'-a'e'\cos(l'-\omega')+a'\frac{e'^2}{2}\Big(1-\cos 2\,(l'-\omega')\Big)\\v'&=n't+\epsilon'+2e'\sin(l'-\omega')+\frac{5}{4}e'^2\sin 2\,(l'-\omega')\end{aligned}$$

whence we have

$$\lambda = -e\cos(l-\omega) + \frac{e^2}{2}\Big(1-\cos 2(l-\omega)\Big)$$

$$\nu = \quad 2e\sin(l-\omega) + \frac{5}{4}e^2\sin 2(l-\omega) \qquad (73)$$

$$\lambda' = -e'\cos(l'-\omega') + \frac{e'^2}{2}\Big(1-\cos 2(l'-\omega')\Big)$$

$$\nu' = \quad 2e'\sin(l'-\omega') + \frac{5}{4}e'^2\sin 2(l'-\omega')$$

From which we find

$$\lambda^2 = \frac{e^2}{2}\Big(1+\cos 2(l-\omega)\Big)$$

$$\lambda'^2 = \frac{e'^2}{2}\Big(1+\cos 2(l'-\omega')\Big)$$

$$\lambda\lambda' = \frac{1}{2}ee'\cos\Big((l-\omega)+(l'-\omega')\Big) + \frac{1}{2}ee'\cos\Big((l-\omega)-(l'-\omega')\Big)$$

$$\nu-\nu' = 2e\sin(l-\omega) - 2e'\sin(l'-\omega')$$

$$(\nu-\nu')^2 = 2(e^2+e'^2) - 2e^2\cos 2(l-\omega) - 2e'^2\cos 2(l'-\omega') + 4ee'\cos\Big((l-\omega)+l'-\omega')\Big) - 4ee'\cos\Big((l-\omega)-(l'-\omega')\Big)$$

$$\lambda(\nu-\nu') = -e^2\sin 2(l-\omega) + ee'\sin\Big((l-\omega)+(l'-\omega')\Big) - ee'\sin\Big((l-\omega)-(l'-\omega'\Big)$$

$$\lambda'(\nu-\nu') = \quad e'^2\sin 2(l'-\omega') - ee'\sin\Big((l-\omega)+(l'-\omega')\Big) - ee'\sin\Big((l-\omega)-(l'-\omega')\Big)$$

and substituting these in the terms of (66) which are effected by them and the second terms of (73) in the second, third and fonrth terms we obtain the portion of this development which is of the order of the squares and products of the eccentricities.

$$
\begin{aligned}
\Theta_{0\cdot 2} =. &+ \frac{m'}{1+m}\cdot\frac{e^2}{8}\Big(1+\cos 2\,(l-\omega)\Big)\sum a^2\frac{d^2A^{(i)}}{da^2}\cos i\,(l-l') \\
&+ \frac{m'}{1+m}\cdot\frac{e'^2}{8}\Big(1+\cos 2\,(l'-\omega')\Big)\sum a'^2\frac{d^2A^{(i)}}{da'^2}\cos i\,(l-l') \\
&- \frac{m'}{1+m}\cdot\frac{1}{2}(e^2+e'^2)\sum i^2A^{(i)}\cos i\,(l-l') \\
&+ \frac{m'}{1+m}\cdot\frac{e^2}{2}\cos 2\,(l-\omega)\sum i^2A^{(i)}\cos i\,(l-l') \\
&+ \frac{m'}{1+m}\cdot\frac{e'^2}{2}\cos 2\,(l'-\omega')\sum i^2A^{(i)}\cos i\,(l-l') \\
&- \frac{m'}{1+m}\cdot ee'\cos\Big((l-\omega)+(l'-\omega')\Big)\sum i^2A^{(i)}\cos i\,(l-l') \\
&+ \frac{m'}{1+m}\cdot ee'\cos\Big((l-\omega)-(l'-\omega')\Big)\sum i^2A^{(i)}\cos i\,(l-l') \\
&+ \frac{m'}{1+m}\cdot\frac{ee'}{4}\cos\Big((l-\omega)+l'-\omega')\Big)\sum aa'\frac{d^2A^{(i)}}{da\,da'}\cos i(l-l') \\
&+ \frac{m'}{1+m}\cdot\frac{ee'}{4}\cos\Big((l-\omega)-(l'-\omega')\Big)\sum aa'\frac{d^2A^{(i)}}{da\,da'}\cos i(l-l') \\
&+ \frac{m'}{1+m}\cdot\frac{e^2}{2}\sin 2\,(l-\omega)\sum ia\frac{dA^{(i)}}{da}\sin i\,(l-l') \\
&- \frac{m'}{1+m}\cdot\frac{ee'}{2}\sin\Big((l-\omega)+(l'-\omega')\Big)\sum ia\frac{dA^{(i)}}{da}\sin i(l-l) \\
&+ \frac{m'}{1+m}\cdot\frac{ee'}{2}\sin\Big((l-\omega)-(l'-\omega')\Big)\sum ia\frac{dA^{(i)}}{da}\sin i\,(l-l') \\
&- \frac{m'}{1+m}\cdot\frac{e'^2}{2}\sin 2\,(l'-\omega')\sum ia'\frac{dA^{(i)}}{da'}\sin i\,(l-l') \\
&+ \frac{m'}{1+m}\cdot\frac{ee'}{2}\sin\Big((l-\omega)+(l'-\omega')\Big)\sum ia'\frac{dA^{(i)}}{da'}\sin i\,(l-l') \\
&+ \frac{m'}{1+m}\cdot\frac{ee'}{2}\sin\Big((l-\omega)-(l'-\omega')\Big)\sum ia'\frac{dA^{(i)}}{da'}\sin i\,(l-l') \\
&+ \frac{m'}{1+m}\cdot\frac{e^2}{4}\sum a\frac{dA^{(i)}}{da}\cos i\,(l-l) \\
&- \frac{m'}{1+m}\cdot\frac{e^2}{4}\cos 2\,(l-\omega)\sum a\frac{dA^{(i)}}{da}\cos i\,(l-l') \\
&+ \frac{m'}{1+m}\cdot\frac{e'^2}{4}\sum a'\frac{dA^{(i)}}{da'}\cos i\,(l-l') \\
&- \frac{m'}{1+m}\cdot\frac{e'^2}{2}\cos 2\,(l'-\omega')\sum a'\frac{dA^{(i)}}{da'}\cos i\,(l-l')
\end{aligned}
$$

$$-\frac{m'}{1+m}\cdot\frac{5}{8}e^2\sin 2(l-\omega)\sum iA^{(i)}\sin i(l-l')$$
$$+\frac{m'}{1+m}\cdot\frac{5}{8}e'^2\sin 2(l'-\omega')\sum iA^{(i)}\sin i(l-l')$$
$$+\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

Reducing by the aid of (64) and (65) and uniting similar terms, we have

$$\Theta_{0\cdot 2} = \frac{m'}{1+m}\cdot\frac{1}{8}\sum\left\{a^2\frac{d^2A^{(i)}}{da^2}-4i^2A^{(i)}+2a\frac{dA^{(i)}}{da}\right\}e^2\cos i(l-l')$$
$$+\frac{m'}{1+m}\cdot\frac{1}{8}\sum\left\{a'^2\frac{d^2A^{(i)}}{da'^2}-4i^2A^{(i)}+2a'\frac{dA^{(i)}}{da'}\right\}$$
$$e'^2\cos i(l-l')$$
$$+\frac{m'}{1+m}\cdot\frac{1}{8}\sum\left\{a^2\frac{d^2A^{(i)}}{da^2}-2(2i+1)a\frac{dA^{(i)}}{da}\right.$$
$$\left.+i(4i+5)A^{(i)}\right\}e^2\cos\Big(i(l-l')+2(l-\omega)\Big)$$
$$+\frac{m'}{1+m}\cdot\frac{1}{8}\sum\left\{a'^2\frac{d^2A^{(i)}}{da'^2}+2(2i-1)a'\frac{dA^{(i)}}{da'}\right. \qquad (74)$$
$$\left.+i(4i-5)A^{(i)}\right\}e'^2\cos\Big(i(l-l')+2(l'-\omega')\Big)$$
$$+\frac{m'}{1+m}\cdot\frac{1}{4}\sum\left\{aa'\frac{d^2A^{(i)}}{dada'}+2ia\frac{dA^{(i)}}{da}-2ia'\frac{dA^{(i)}}{da'}\right.$$
$$\left.-4i^2A^{(i)}\right\}ee'\cos\Big((i-1)(l+l')+2l-(\omega+\omega')\Big)$$
$$+\frac{m'}{1+m}\cdot\frac{1}{4}\sum\left\{aa'\frac{d^2A^{(i)}}{dada'}-2ia\frac{dA^{(i)}}{da}-2ia'\frac{dA^{(i)}}{da'}\right.$$
$$\left.+4i^2A^{(i)}\right\}ee'\cos\Big((i+1)(l-l')-(\omega-\omega')\Big)$$

This may be further simplified by means of (70), thus

$$a'\frac{dA^{(i)}}{da'}=-A^{(i)}-a\frac{dA^{(i)}}{da}$$

whence we have by the theory of homogeneous functions

$$aa'\frac{d^2A^{(i)}}{dada'}=-a\frac{dA^{(i)}}{da}-a^2\frac{d^2A^{(i)}}{da^2}$$

and
$$a'^2\frac{d^2A^{(i)}}{da'^2}=2A^{(i)}+2a\frac{dA^{(i)}}{da}+a^2\frac{d^2A^{(i)}}{da^2} \qquad (75)$$

which may be substituted in the above and thus eliminate the derivatives of $A^{(i)}$ with respect to a'.

We will now consider the second and third terms of (63) which we will represent by $Q_{0\cdot 3}$, thus

$$\Theta_{0\cdot 3} = -\frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa'\sum B^{(i-1)}\cos i\,(l-l')$$
$$+\frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa'\sum B^{(i-1)}\cos\Big(i\,(l-l')+2\,(l'-\tau)\Big)$$

These functions involve the inclination of the orbit of (m) to that of (m'), and are already of the second order. It will therefore suffice for our present purpose to develop them according to the first power of the eccentricities. Since $B^{(i-1)}$ is a function of a and a', we shall have as in the case of $A^{(i)}$

$$\Theta_{0\cdot 3} = -\frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa'\sum B^{(i-1)}\cos i\,(l-l')$$
$$-\frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa'\lambda\sum a\frac{dB^{(i-1)}}{da}\cos i\,(l-l')$$
$$-\frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa'\lambda'\sum a'\frac{dB^{(i-1)}}{da'}\cos i\,(l-l')$$
$$+\frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa'\,(\nu-\nu')\sum iB^{(i-1)}\sin i\,(l-l')$$
$$+\frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa'\sum B^{(i-1)}\cos\Big(i\,(l-l')+2\,(l'-\tau)\Big)$$
$$+\frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa'\lambda\sum a\frac{dB^{(i-1)}}{da}\cos\Big(i(l-l')+2\,(l'-\tau)\Big)$$
$$+\frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa'\lambda'\sum a'\frac{dB^{(i-1)}}{da'}\cos\Big(i(l-l')+2\,(l'-\tau)\Big)$$
$$-\frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa'\,[\nu-\nu')\sum iB^{(i-1)}$$
$$\sin\Big(i(l-l')+2\,(l'-2\tau)\Big)$$

Substituting the values of λ, λ' and $\nu-\nu'$ as given by (68) we obtain by the aid of (64) and (65)

$$\Theta_{0\cdot 3} = -\frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa'\sum B^{(i-1)}\cos i\,(l-l')$$
$$+\frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa'\sum a\frac{dB^{(i-1)}}{da}e\cos\Big(i\,(l-l')+l-\omega\Big)$$
$$+\frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa'\sum a'\frac{dB^{(i-1)}}{da'}e'\cos\Big(i\,(l-l')+l'-\omega'\Big)$$
$$-\frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa'\sum 2iB^{(i-1)}e\cos\Big(i\,(l-l')+l-\omega\Big)$$

$$+\frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa'\sum 2iB^{(i-1)}\,e'\cos\Big(i\,(l-l')+l'-\omega'\Big)$$

$$+\frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa'\sum B^{(i-1)}\cos\Big(i\,(l-l')+2\,(l'-\tau)\Big)$$

$$-\frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa'\sum a\,\frac{dB^{(i-1)}}{da}\,e$$
$$\cos\Big(i(l-l')+2\,(l'-\tau)+l-\omega\Big)$$

$$-\frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa'\sum a'\,\frac{dB^{(i-1)}}{da'}\,e'$$
$$\cos\Big(i\,(l-l')+2\,(l'-\tau)+l'-\omega'\Big)$$

$$+\frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa'\sum 2iB^{(i-1)}\,e$$
$$\cos\Big(i\,(l-l')+2\,(l'-\tau)+l-\omega\Big)$$

$$-\frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa'\sum 2iB^{(i-1)}\,e'$$
$$\cos\Big(i\,(l+l')+2\,(l'-\tau)+l'-\omega'\Big)$$

and grouping similar terms together we have

$$\Theta_{0\cdot 3}=\frac{m'}{1+m}\cdot\frac{1}{2}\eta^2 aa'\Big\{-\sum B^{(i-1)}\cos i\,(l-l')$$
$$+\sum B^{(i-1)}\cos\Big(i(l-l')+2\,(l'-\tau)\Big)$$
$$+\sum\Big(a\,\frac{dB^{(i-1)}}{da}-2iB^{(i-1)}\Big)$$
$$e\,\cos\Big(i\,(l-l')+l-\omega\Big)$$
$$+\sum\Big(a'\frac{dB^{(i-1)}}{da'}+2iB^{(i-1)}\Big)$$
$$e'\cos\Big(i\,(l-l')+l'-\omega'\Big)$$
$$-\sum\Big(a\,\frac{dB^{(i-1)}}{da}-2iB^{(i-1)}\Big)$$
$$e\cos\Big(i\,(l-l')+2\,(l'-\tau)+l-\omega\Big)$$
$$-\sum\Big(a'\frac{dB^{(i-1)}}{da'}+2iB^{(i-i)}\Big)$$
$$e'\cos\Big(i\,(l-l')+2\,(l'-\tau)+l'-\omega'\Big\}\Big)$$

This may be further simplified by eliminating $a' \frac{dB^{(i-1)}}{da'}$; thus, since $B^{(i-1)}$ is a homogeneous function of a and a' of -3 dimensions, we have

$$a \frac{dB^{(i-1)}}{da} + a' \frac{dB^{(i-1)}}{da'} = -3B^{(i-1)}$$

whence

$$a' \frac{dB^{(i-1)}}{da'} = -3B^{(i-1)} - a \frac{dB^{(i-1)}}{da}$$

which substituted in the fourth and sixth terms of the above gives

$$\begin{aligned}
\Theta_{0\cdot 3} = \frac{m'}{1+m} \cdot \frac{1}{2} \eta^2 a a' \Big\{ & - \sum B^{(i-1)} \cos i(l - l') \\
& + \sum B^{(i-1)} \cos \Big(i(l-l') + 2(l'-\tau) \Big) \\
& + \sum \Big(a \frac{dB^{(i-1)}}{da} - 2iB^{(i-1)} \Big) \\
& \qquad e \cos \Big(i(l-l') + l - \omega \Big) \\
& + \sum \Big((2i-3) B^{(i-1)} - a \frac{dB^{(i-1)}}{da} \Big) \\
& \qquad e' \cos \Big(i(l-l') + l' - \omega' \Big) \\
& - \sum \Big(a \frac{dB^{(i-1)}}{da} - 2iB^{(i-1)} \Big) \qquad (76) \\
& \qquad e \cos \Big(i(l-l') + 2(l'-\tau) l - \omega \Big) \\
& - \sum \Big((2i-3) B^{(i-1)} - a \frac{dB^{(i-1)}}{da} \Big) \\
& \qquad e' \cos \Big(i(l-l') + 2(l'-\tau) + l' - \omega' \Big) \Big\}
\end{aligned}$$

Adding these parts together we have

$$\Theta = \Theta_{0\cdot 1} + \Theta_{0\cdot 2} + \Theta_{0\cdot 3} \qquad (77)$$

which is the development of Θ extended to the squares and products of the eccentricities of the orbits. In a similar manner we may proceed to extend the development so as to include the third and higher powers of the eccentricities—an operation which pre-

sents no other difficulties than those which result from the magnitude of the calculations which, however, become extremely complicated as we rise in the order of approximations.

The inclinations of the orbits of the planets to each other are quite small, and therefore the terms of (76) which involve η^2 and the first power of the eccentricity, are also extremely small, and when the development is carried to the third or fourth order of small quantities, they may be regarded as quite insensible except under certain peculiar circumstances, as in the case of the theory of the motion of the Earth and Venus, where the inequality arising from the mutual inclination of their orbits, amounts to 2″.9 for Venus and 2″.15 for the Earth.

NOVA PERSEI.

A. E. DOUGLASS.

For Popular Astronomy.

The new star in Perseus was independently (though tardily) discovered by me on February 23 at 9:30 P. M. ($16^h 30^m$ G. M. T.). It was then a shade brighter than Capella and was recorded as being magnitude 0.1. I had seen it on the 21st or 22d but had not realized its character; for Capella had long been my particular star for getting observations on atmospheric currents and the condition of the atmosphere each evening. And on either the 21st or 22d (undoubtedly the latter as I now know the star's brightness at that time) I had remarked with surprise that there was an exceedingly good star in Perseus for this very purpose and thought it most strange that I had never noticed it before.

But after really recognizing the new star, a direct vision Browning spectroscope was tried on it from 11:45 to 12:10 on February 23 and and an ordinary absorption spectrum observed. Notwithstanding the low dispersion of the spectroscope the dark lines appeared broad, perhaps broad enough to be called narrow bands. There were two dense ones in the red, a faint one in the yellow, two very dense ones in the green and a very broad band in the blue.

The star was also examined with a power of 528 to see if it exhibited any sensible size but no disk could be seen beyond that due to the currents in the atmosphere. Chart photographs were

also made of it in the only available camera, that is the one of very short focus and wide aperture used in photographing the zodiacal light.

On February 24th at about 8^h the brightness of the star was estimated to be 0.6 magnitude. At the very first glance through the spectroscope the remarkable change from the preceding night was manifest. The bright lines and shadings formed a marked contrast with the plain spectrum previously seen. Chart photographs were taken of it on this night also in small cameras and in the 24-inch telescope (385.7 inches focus). These plates show two or more Durchmusterung stars as well as the Nova.

On February 25th the magnitude af the star had decreased to closely 1.0 but the spectrum seemed to be much the same as on the preceding night, the contrasts between bright and dark parts being somewhat more strongly marked. As it was learned then that the star had been discovered on the 21st and that it was being carefully observed at other stations better equipped for the purpose, special attentoin to it was thenceforth discontinued.

LOWELL OBSERVATORY,
March 20, 1901.

THE NEW STAR IN PERSEUS.*

GEORGE E. HALE.

The first news of Anderson's discovery of a new star in Perseus was received at this Observatory on February 24. An examination of the region near the star, made that evening with the 40-inch telescope, failed to show any evidence of nebulosity, but the bright moonlight would have rendered a faint nebula invisible. At that time the magnitude of the star appeared to be about 0.5. Its color was yellow, with a decided reddish cast, very similar to that of α Orionis. Very little time was spent in examining the spectrum visually, as it was felt that photographs would be more valuable than drawings based on micrometer measures. We had fortunately just received a fresh supply of Erythro plates through the kindness of the International Color-Photo Company of Chicago, and it was therefore possible to photograph the entire spectrum from $H\alpha$ to $H\iota$. Beyond this point in the ultra-violet the absorption of the 40-inch objective greatly enfeebles the spectrum, which is still further weakened by the lack of perfect achromatism in this region.

* The Yerkes Observatory of the University of Chicago, Bulletin No. 16.

Photographs of the spectrum have been obtained by Mr. Ellerman as follows:

Date.	No. of Plates.	Dispersion.	Region.
1901, Feb. 24	5	3 prisms	$H\beta$ to $H\gamma$, Bruce spectrograph
24	5	3 prisms	D to 4400
24	1	3 prisms	$H\alpha$ to 4500
25	3	3 prisms	$H\beta$ to $H\gamma$, Bruce spectrograph
25	3	3 prisms	D to 4400
25	3	1 prism	5700 to 3700
25	1	1 prism	$H\alpha$ to 3900
26	3	3 prisms	D to 4400
26	1	1 prism	$H\alpha$ to 3900
27	8	3 prisms	D to 4400
27	1	3 prisms	$H\alpha$ to 4500
27	6	1 prism	5700 to 3700
28	5	1 prism	5700 to 3700
28	2	1 prism	$H\alpha$ to 3900
28	3	3 prisms	D to 4400
Mar. 4	3	1 prism	5700 to 3700
4	1	1 prism	$H\alpha$ to 3900
6	2	3 prisms	D to 4400
6	1	3 prisms	$H\beta$ to $H\gamma$
6	1	1 prism	5700 to 3700
11	3	3 prisms	D to 4400
11	1	1 prism	5700 to 3700

The comparison spectra which appear on these plates are those of titanium, hydrogen and sodium.

On February 24 and 25 Mr. Ritchey photographed the region of the Nova with the 40-inch telescope and color screen. In order to obtain a sufficient number of comparison stars the plates were given an exposure of one hour. The light of the Nova was intercepted by a small movable occulting disk, with which four (for the second plate, five) very brief exposures were given at intervals of about fifteen minutes. The total exposure for the Nova was probably about half a second. In the resulting photographs, the images of the Nova and the neighboring stars (of which more than forty appear in a region 12′ square) are small and appear to be well adapted for measurement. Through the kindness of Director Rees, these plates will be measured at the Columbia College Observatory. The position of the Nova was measured micrometrically by Professor Burnham on March 3.

The wedge photometer used with the 40-inch telescope in the determination of standards of faint stellar magnitudes has been employed by Mr. Parkhurst in measuring the brightness of the Nova. Hitherto objectives of one and two inches aperture have sufficed, but as the Nova decreases in brilliancy it will be followed

with the 12-inch and 40-inch telescopes. A preliminary reduction gives the following magnitudes:

Date.	Mag.	Date.	Mag.
1901, Feb 25	1.0	1901, Mar. 3	2.7
26	1.1	4	2.8
27	2.0	5	2.7
28	1.9	6	3.1

A photograph of the spectrum (G 440) taken with the one prism spectrograph on February 28 has been measured by the writer. The resulting wave-lengths of the lines and bands, computed by the aid of Cornu-Hartmann formulæ, furnished data for attaching a scale to an enlargement of the photograph reproduced in Fig. 3, Plate III.

Inspection of the photograph will show that the spectrum is very similar to the earlier spectrum of Nova Aurigæ. The hydrogen lines, notably C (Fig. 2) and F, are bright and very broad. The dark lines superposed upon them (not shown in the cut) are probably reversals caused by the absorption of an outer layer of cooler gas at lower pressure.

On the more refrangible side the hydrogen lines are accompanied by dark lines, just as was the case with Nova Aurigæ. As Wilsing has shown, this is doubtless due to the great pressure under which the radiation occurs. The bright sodium line has broadened into a band, on which appear the two dark D lines (Fig. 1). These appear on the photographs, and are clearly visible in visual observations with a three-prism spectroscope. As the titanium poles were moistened with a weak solution of sodium chloride, the comparison spectrum contains the bright sodium lines. Thus the motion of the star in the line of sight can be measured. Some preliminary determinations indicate that the Nova is moving away from the Earth at a low velocity.

The helium line D_3 seems to be present as a dark line, lying close to the bright sodium band on the more refrangible side (Fig. 1). The bright calcium lines H and K are notable for their great breadth and for the narrow lines of reversal which traverse them. The chief nebular line seems to be present (λ 5002—5041) and a fainter line or band (λ 4911 — 4988) covers the region of the second nebular line. The *b* group of magnesium is doubtless represented by the very bright band λ 5154 — 5204. The green coronal line (λ 5303) would fall near the more refrangible edge of a bright band in the spectrum of the Nova.

Further results, based upon measurements of photographs taken with the three-prism spectrograph, will be given in a subsequent paper.

Note added March 18.—A comparison of photographs taken on March 4 and March 15 shows that the dark lines on the more refrangible edge of the bright hydrogen lines continue to increase in sharpness. At first single and rather diffuse, they have become sharply defined double lines. K is much fainter than before, and *b* is apparently decreasing in intensity.

March 12, 1901.

TOTAL SOLAR ECLIPSE, MAY 17-18, 1901.

H. C. WILSON.

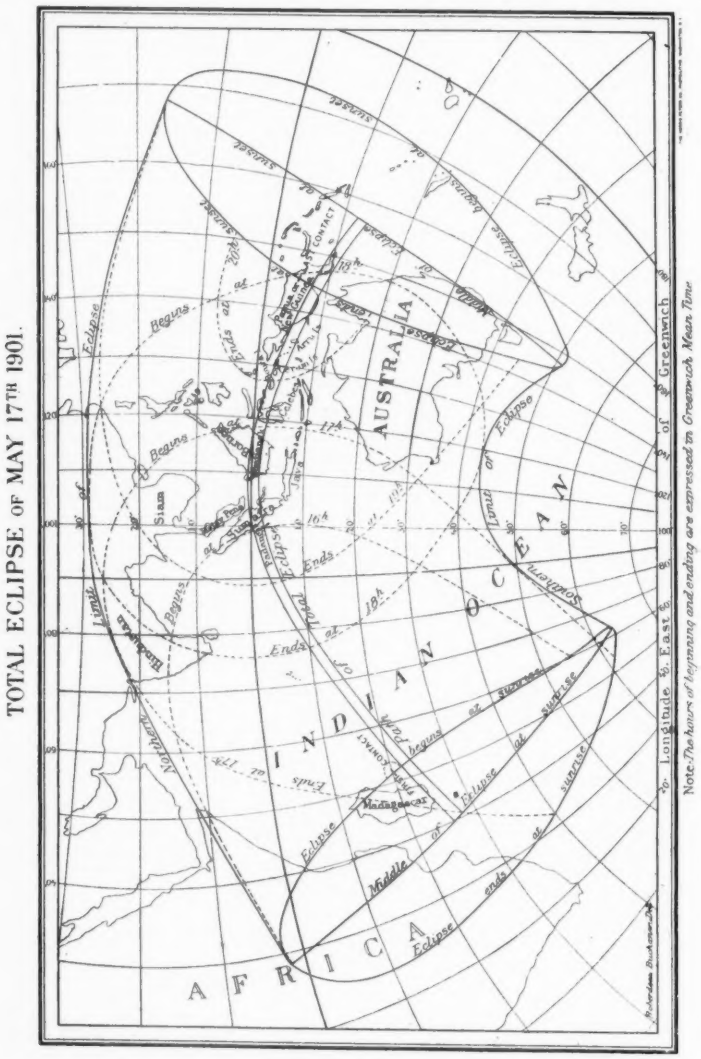
FOR POPULAR ASTRONOMY.

This eclipse, it will be apparent from the accompanying diagrams, will be visible only upon the other side of the world to most of our readers. The path of totality lies mostly upon water, touching land only as it crosses the island of Mauritius, those of the Malay Archipelago and New Guinea. According to the "Informations for Observing Parties," issued by a committee from the Naturalists' Society at Batavia, the Mentawi Islands and New Guinea, being inhabited by untrusty savages and lacking in every sort of accommodation, are not to be taken into consideration for making observations. The east coast of Sumatra, the west and east coasts of Celebes and the more easterly islands—Amboyna and Saparua excepted—may also be deemed less suitable for observation purposes, owing to local conditions and circumstances.

The best opportunity is afforded by the west coast of Sumatra, where Padang, the residence of the Governor, is a considerable place, with a telegraph office and four hotels, and is well in toward the center-line of totality. A railroad connects Padang with a few inland points at higher levels, and along this railroad probably most of the observing parties will be distributed, since the facilities for inland transportation are otherwise very poor. Unfortunately the chances for clear weather in this region are only about 1 in 2, and the observers ought to be as widely scattered as possible along the path of totality, while in all probability they will nearly all be in the vicinity of the railroad running out of Padang.

The United States government eclipse expedition sailed from San Francisco, Feb. 16, on board the transport "Sheridan," which was to take the members of the party as far as Manila. There the party was to be met by one of the men of war of the

Asiatic Squadron and conveyed to Sumatra. They expected to reach Padang by the first of April, and so to have plenty of time



for the selection of stations and the delicate adjustments of the various pieces of apparatus to be used in observing the eclipse.

The expedition is under the charge of Professor A. N. Skinner of the U. S. Naval Observatory. Accompanying him from that Observatory are Messrs. W. S. Eichelberger, F. B. Littell, G. H. Peters, L. E. Jewell and W. W. Dinwiddie. From other observatories are Professor E. E. Barnard, of the Yerkes Observatory; Dr. W. J. Humphreys, of the University of Virginia; Dr. S. A. Mitchell, of Columbia University, N. Y.; Dr. N. E. Gilbert, of Johns Hopkins University; H. H. Curtis, of the Leander McCormick Observatory; C. G. Abbott of the Smithsonian Institution; and Professor W. J. Hussey of Lick Observatory.

It is expected that Professor Barnard will be located at Solok (wrongly printed Sotok in the diagram) 1300 feet above the level of the sea. He will endeavor to photograph the corona on a very large scale, using the coelostat which he employed so successfully at Wadesboro, N. C., last year. The long duration of totality during this eclipse, $6^m\,30^s$ at the central line near Padang, makes it possible to give much longer exposures than have been tried before, so that much more may be expected from the large scale photographs than was obtained in 1900. The following statement given by Professor Barnard to the editor of *Camera Craft*, San Francisco, just before the party sailed, tells in an interesting manner what he expects to do:

"Those who have handled large plates know the difficulty of developing them successfully but the development of 25 x 30 plates of last May showed that it would be possible to develop much larger ones if they could be successfully handled in exposures on the corona. It was decided that in this eclipse it would be possible to handle in exposure and development a plate as large as forty inches square.

"As every second in a total eclipse of the Sun is of the utmost importance it became necessary to devise a method of handling such plates with the least possible loss of time. It was proposed to not only use 40 x 40 plates but also to use two other sizes smaller, viz., 30 x 30, and 14 x 17 inches.

"It became a serious question how to handle these different sized large plates, but it was finally decided to make a frame for the 30 x 30 plate-holders, which have kits for 14 x 17 plates. This is to be made of the same width as the 40 x 40 plate-holder. They are to be fastened rigidly together so that they can be moved up and down between two vertical posts in grooves. The heavy weights of these plates and holders are relieved by suitable counterpoises, the whole made to slide up and down between the two posts just as a window-sash may be raised or lowered.

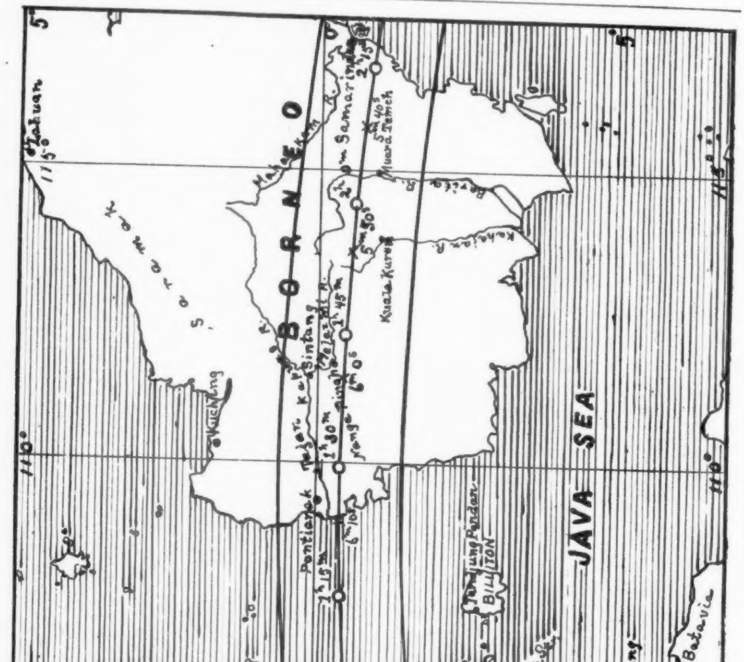


CHART OF ECLIPSE TRACK ACROSS SUMATRA AND BORNEO.

Each plate can therefore be brought at once into position for exposure. As the telescope will be a horizontal one the plates will be in a vertical position.

"The instrument to be used is a Coelostat. With this instrument everything remains stationary except the polar axis, which is rotated at the rate of one revolution in forty-eight hours (twice as slow as the ordinary motion of an equatorial telescope). This axis carries a fifteen-inch, plane, silvered glass mirror, which is placed parallel to the polar axis. This mirror reflects the Sun's light into a stationary six-inch photographic lens, which has a focal length of 61½ feet. At the focus of this lens is built a darkroom, in which the plates are exposed. This darkroom is connected with the six-inch mirror by a horizontal tube made of paper over a slight wood frame-work. The observer is, of course, in the room where the plates are exposed, and can see the image as it falls on the plates. The large plates to be used have been made especially by the Cramer Dry Plate Company of St. Louis, and will be heavily backed to prevent halation.

"On account of the long focus (aperture to focus = 1 : 123) and the use of the mirror, the exposures required will be much longer than with ordinary telescopes. The great duration of totality at the present eclipse—at our station, 355 seconds—will therefore, be especially suited for the Coelostat, as a number of plates can be exposed much longer than usual.

"The great plate, 40 x 40 will have an exposure of 150 seconds another will be exposed sixty seconds, and others with less exposures down to one-half second.

"The large plate will cover a region one degree and a half all around the Sun. The long exposure plate is expected to show any star as small as the eighth magnitude that lies in this region. If, therefore, an intra-mercurial planet as bright as the eighth magnitude lies within 1½° of the Sun, it will be shown on the big plate.

"The exposed plates are to be developed with pyro, as I found that it gave the best results for the eclipse plates of last May."

At Fort de Kock, on the railroad near the northern border of the shadow-path Mr. Peters expects to use the 40-foot photoheliograph lenses of the Naval Observatory for photographing the corona. Mr. Jewell and Dr. Humphreys will use a concave grating of 30 feet focal length, with a ruled surface of 3½ by 3 inches and with no slit, in order to photograph the flash spectrum. They will have also a concave grating of 10 feet focus and a visual lens.

Dr. Mitchell and Mr. Littell will operate near the central line, using objective gratings, one of these with a very long slit for the purpose of determining the rotation of parts of the corona.

Dr. Gilbert is charged with the task of carrying out the suggestion of Professor Wood of the University of Wisconsin, which was referred to in this magazine a few months since, namely, the use of a Nicol prism in connection with the spectroscope to separate the polarized from the unpolarized rays of the corona, so as to possibly bring out the dark lines in the spectrum of the corona.

From *The Observatory* we learn that Mr. E. W. Maunder of the Royal Observatory, Greenwich, accompanied by Mrs. Maunder, will go to the island of Mauritius, east of Madagascar, and join forces with Mr. Claxton, a former colleague at Greenwich, in observing the eclipse from the Royal Alfred Observatory. They will attempt to photograph the corona with 4-inch photoheliographs and to photograph the coronal and "flash" spectra with the prismatic camera used so successfully by Mr. Evershed in India in 1898.

An observing party consisting of Mr. Newall, Mr. Dyson and Mr. Atkinson, will proceed to Sumatra. Mr. Newall represents the Joint Permanent Eclipse Committee, Mr. Dyson goes as representative from the Royal Observatory, Greenwich, and Mr. Atkinson, who rendered great help to the expedition at Ovar last year, has generously volunteered to undertake the lengthier journey to give similar help on this occasion. The observations projected by Mr. Newall are: (1). The determination of the rotation of the corona; (2). By means of a grating to photograph coronal rings corresponding to different lines; (3) Polariscopic observations similar to those made at Algiers in May 1900. His program also includes the "flash," and some other of the observations made last year. Mr. Dyson has charge of the Thompson 9-inch object-glass, with magnifier, to obtain photographs on a scale of 4 inches to the Sun's diameter; of a double tube with rapid lenses, to show the coronal streamers and the extension; and of a quartz spectroscope, kindly lent by Capt. Hills for the photography of the spectrum of the corona and of the "flash" in the ultra-violet part of the spectrum.

The Lick Observatory expedition under the charge of Secretary C. D. Perrine will be located somewhere in the vicinity of Padang and will devote its attention to photographs of the corona and the region surrounding the Sun.

Professor D. P. Todd of Amherst College Observatory will use his automatic combination of cameras on the Island of Singkep,

off the east coast of Sumatra, the principal place of which is marked Dabok on the chart.

The eclipse at Padang begins at $10^h\ 45^m$ on the morning of May 18, local time, and ends at $1^h\ 57^m$ in the afternoon. Totality begins at $18^m\ 49^s$ and ends at $25^m\ 03^s$ afternoon, so that the Sun is at its greatest altitude and the duration is $6^m\ 14^s$, a longer duration than has been observed for many years past and the equal of which will not occur for many years to come. It is greatly to be hoped that the weather conditions will not disappoint those who have undertaken such a long and tedious voyage, at great expense, for the purpose of utilizing a rare opportunity to add to our knowledge of those mysterious forces which play about the Sun.

PLANET NOTES FOR MAY.

H. C. WILSON.

Mercury will be at superior conjunction May 14 and therefore will not be visible to the unaided eye during this month. The planet will be at perihelion May 18; in conjunction with Venus May 18; and in conjunction with Neptune May 31.

Venus having just passed superior conjunction will not be visible for the first few days of the month, but it will not be many days before we shall be able to catch the first glimmer of the planet as evening star, shortly after sunset and close to the sunset point.

Mars is in most convenient position for study in the early evening, near the meridian and at a high altitude. We have watched the planet with interest as it has completed the great loop in its path through Leo, and now its course will be almost straight away along the ecliptic. On May 4 in the morning Mars will pass by Regulus, the planet being then 1° 38′ north of the star. Mars will be at quadrature 90° east from the Sun, May 28, and in conjunction with the Moon May 25.

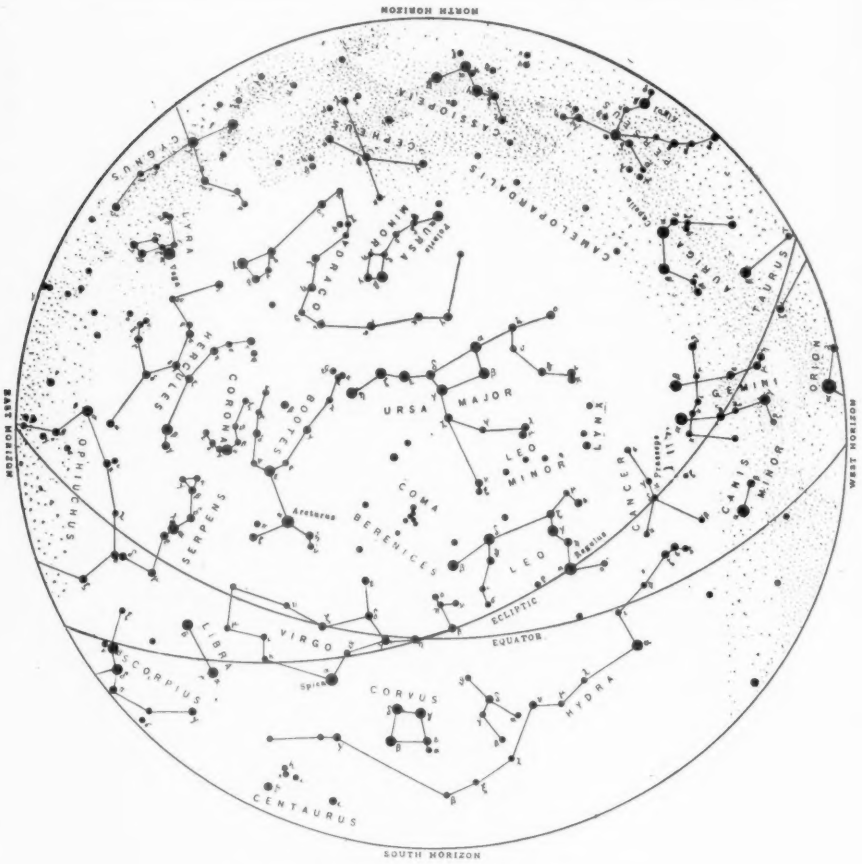
Jupiter and *Saturn* may be best seen in the morning hours, but always under unsatisfactory conditions, because of their low altitude. The Moon will be in their vicinity May 8. These planets are both in the constellation Sagittarius.

Uranus is in Scorpio and may be observed about midnight. Its low altitude in our latitude, will prevent satisfactory views except on rare occasions.

Neptune is too near conjunction to be observed well during this month.

The Moon.

Phases.		Rises. (Central Standard Time at Northfield Local Time 13m less).	Sets.
		h m	h m
May 3	Full Moon	7 35 P. M.	5 23 A. M.
11	Last Quarter	12 52 A. M.	11 50 "
17	New Moon	4 12 "	7 16 P. M.
24	First Quarter	11 25 "	12 40 A. M.



THE CONSTELLATIONS AT 9 P. M. MAY, 1, 1901.

Occultations Visible at Washington.

Date. 1901.	Star's Name.	Magnitude.	IMMERSION. Washington M.T. h m	Angle from N pt. °	EMERSION. Washington M. T. h m	Angle from N pt. °	Duration. h m
May 1	*i* Virginis	5.5	8 44	172	9 34	244	0 50
4	λ Libræ	5.0	8 28	91	9 36	302	1 08
4	ω^1 Scorpii	4.1	17 28	86	18 35	270	1 07
4	ω^2 Scorpii	4.6	17 59	140	18 39	217	0 39
8	B.A.C. 6658	7.3	11 44	123	13 00	225	1 16
24	14 Sextantis	6.6	6 05	87	7 17	233	1 12
24	19 Sextantis	6.0	10 33	124	11 35	283	1 02
25	55 Leonis	6.0	8 00	133	9 22	287	1 22
25	p^2 Leonis	6.2	13 01	89	13 53	310	0 52
30	B.A.C. 4896	6.6	10 54	26	11 08	7	0 14

Elements of Asteroids (457) to (463).—In *Astronomische Nachrichten* No. 3698 Professor J. Bauschinger gives the following elements of the asteroids recently discovered and numbered 457 to 463, computed at the Royal Astronomical "Rechen-Institut" at Berlin. The epochs are in Berlin mean time:

Asteroid	(457) Alleghenia	(458) [1900 *FK*]	(459) [1900 *FM*]
Epoch	1900, Oct. 28.5	1900, Oct. 28.5	1900, Oct. 22.5
M =	351° 00′ 33″.8	337° 54′ 29″.8	348° 14′ 27″.2
ω =	129 08 30 .3	272 45 25 .4	17 55 30 .4
Ω =	250 37 59 .4	135 55 33 .5	29 41 44 .2
i =	12 52 30 .6	12 36 38 .0	10 22 40 .6
ϕ =	10 20 02 .3	14 11 27 .8	12 19 50 .0
μ =	651″.8517	684″.198	832″.007
log a =	0.490572	0.476550	0.419920
Computer:	Dr. Paetsch.	Dr. Riem.	Prof. Bauschinger.

Asteroid.	(460) [1900, *FN*]	(461) [1900 *FP*]	(462) [1900 *FQ*]
Epoch.	1900, Oct. 22.5.	1900, Oct. 22.5.	1900, Nov. 20.0.
M =	14° 38′ 31″.6	310° 01′ 24″.7	32° 16′ 04″.9
ω =	163 33 31 .3	301 27 38 .2	251 09 49 .3
Ω =	205 36 09 .4	156 33 33 .1	105 44 14 .0
i =	4 35 30 .1	1 22 25 .1	3 10 29 .5
ϕ =	5 53 49 .8	11 54 22 .6	4 53 28 .5
μ =	791″.305	624″.571	729″.957
log a =	0.434442	0.502950	0.457806
Computer:	Prof. Bauschinger.	Prof. Bauschinger.	Herr Berberich.

Asteroid (463) [1900 *FS*]
Epoch 1900 Oct. 31.5

M = 19° 49′ 32″.2
ω = 325 32 12 .4
Ω = 36 26 08 .0
i = 13 29 56 .1
ϕ = 12° 42′ 56″.7
μ = 960″.910
log a = 0.378216
Computer: Herr Berberich.

New Elements of Asteroid (196) Philomela.—In *Astr. Nach.* No. 3688 Dr. P. V. Neugebauer of Breslau gives the following new elements of Philomela, based upon observations in the years 1879, 1881, 1884, 1885, 1892, 1893, 1895 and 1897:

Epoch 1901 April 9.0 Berlin mean time.

M = 240° 25′ 11″.63
ω = 237 19 9 .01
Ω = 73 19 44 .73 } 1900.0
i = 7 17 0 .63
ϕ = 1 13 48 .14
μ = 646″.03772
log a = 0.4931658

GENERAL NOTES.

Those in charge of this publication do not hold themselves responsible for the views of contributors. Care is taken not to print opinions known to be wrong, yet liberty is given to publish views that are not yet fully established, if probability is in their favor.

We have added eight pages to the size of this number in order to publish Dr. Morrison's important article on perturbations and the perturbative function. This continued article on this difficult theme has been repeatedly asked for by stu-

dents of astronomy, and Dr. Morrison with much pains and care has written down to the level of college mathematics, for the benefit of those who are not enough experienced in higher analysis.

Readers who are not acquainted with college mathematics sufficiently to read Dr. Morrison's article in this number, will please remember that there are many others who can, and who will be greatly helped by it in their studies. The eight added pages ought to be compensation if any such feel they have suffered loss.

We have been surprised, repeatedly, that some students who have knowledge of the methods of higher analysis persistently claim that the difficult problems of astronomy, like those presented by Dr. Morrison, may be solved by the simple processes of algebra, geometry and trigonometry, completely and generally. It seems to us that such ought to know better.

Amherst College Solar Eclipse Expedition.—In a private letter, bearing date March 25, 1901, from Port Said, Professor D. P. Todd, of Amherst College Observatory writes that the Amherst College expedition in his "charge, reached Algiers March 18 and Port Said today," two days ahead of the time planned, and it is expected that the expedition will reach Japan on or before April 15. Professor Todd then thought he should locate on the island of Singkep about 170 miles southeast of Singapore toward Banka and Java. There is some probabillty that he might choose Pontianak which is on the west coast of the island of Borneo.

Besides an automatic camera for taking 150 negatives of the corona on glass, he has a 12-inch reflector of speculum metal, 17-ft. focus, to be revolved by means of his new glycerine clock, which he found so well adapted to this kind of work in his Japanese expedition of 1896, and in the Tripoli expedition of last year. He puts large dependence on the work of the last instrument. The camera of the 12-inch is fitted with an improved rotating occulter for variable exposure on different regions of the corona. His other cameras are both reflecting and refracting, especially a double polariscope fitted up by Dr. Wright of Yale University, who is the chief American authority on the polarization of the corona. Mrs. Todd accompanies the expedition, also their daughter who is a member of the class of 1902 at Vassar College.

Through the liberality of Mr. William E. Dodge, Dr. Britton of the New York Botanical Garden, Bronx Park, is enabled to send out with the expedition Mr. Percy Wilson, as naturalist and collector, in a region hitherto but little investigated.

The Benjamin Apthorp Gould Fund.—Since the appropriations announced in *A. J.* 477 the following additional grants have been made: to Mr. John A. Parkhurst, $30; to Dr. Herman S. Davis, $500; to Paul S. Yendell, $225; to Professor Simon Newcomb, $25. A considerable additional amount of income has accrued, for the distribution of which applications are awaited. These applications may be made by letter to any of the Directors undersigned stating the amount desired, the nature of the proposed investigation, and the manner in which the money is to be expended. The following information is given for the guidance of applicants:

The BENJAMIN APTHORP GOULD FUND was established in 1897 by MISS ALICE BACHE GOULD, to advance the science of astronomy, and to honor the memory of her father by ensuring that his power to accomplish scientific work shall not

end with his death. The principal is $20,000, vested in the National Academy of Sciences as Trustee. The income is to be administered by the undersigned and their successors to assist the prosecutions of researches in astronomy.

In recognition of the fact that during DR. GOULD'S lifetime his patriotic feeling and ambition to promote the progress of his chosen science were closely associated, it is preferred that the Fund should be used primarily for the benefit of investigators in his own country or of his own nationality. But it is further recognized that sometimes the best possible service to American science is the maintenance of close communion between the scientific men of Europe and of America, and that therefore, even while acting in the spirit of the above restriction, it may occasionally be best to apply the money to the aid of a foreign investigator working abroad.

In all cases work in the astronomy of precision will be preferred to work in astrophysics, both because of DR. GOULD'S especial predilection and because of the present existence of generous endowments for astrophysics.

Finally, the BENJAMIN APTHORP GOULD FUND is intended for the advancement and not not for the diffusion of scientific knowledge, and it is to be used to defray the actual expenses of investigation, rather than for the personal support of the investigator during the time of his researches, without absolutely excluding the latter use under exceptional circumstances.

In addition to the above call for applications the Dirrctors desiring to stimulate the participation of American astronomers in the attempt to bring up the arrears of cometary research, offer to them the sum of $500 for computation of the "definitive" orbits of comets (see list in *A. J.* 493, p. 104); this sum to be distributed at the average rate of $100 for each computation,—the amount to vary according to the relative difficulty of the computation, and to be determined by the Directors of the GOULD FUND. Computers should promptly notify the Directors of their participation or desire to participate, and manuscripts should be submitted not much later than July 1, 1902.

LEWIS BOSS, SETH C. CHANDLER, ASAPH HALL.

1901, March.

Eros a Double Planet?—In *Astronomische Nachrichten* No. 3698 Mr. C. André of the Observatory of Lyons, France, announces some very striking conclusions drawn from the light variations of Eros as observed at Lyons. Four observers have studied these variations assiduously on each night when possible, from sunset until the planet's altitude became too low, comparing the planet by the method of steps with a series of neighboring stars. As a result the curve of light variation is found to have a double period, with two approximately equal minima and two equal maxima, but with unequal intervals between them. If the times of the successive minima be designated by m_1, m_2, m_3.....and those of the maxima by m_1, m_2, m_3....., the intervals are found to be

$$m_2 - m_1 = 2^h\ 51^m, \qquad M_2 - M_1 = 2^h\ 50^m$$
$$m_3 - m_2 = 2\ \ 24\ , \qquad M_3 - M_2 = 2\ \ 26$$

The duration of the increase of light is about the same in both branches of the curve

$$M_1 - m_1 = 1^h\ 20^m;$$
$$M_2 - m_2 = 1\ \ 18\ ,$$

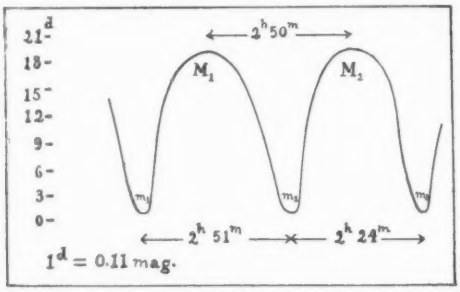
but that of the diminution of light is quite unequal in the two cases,

$$m_2 - M_1 = 1^h\ 31^m;$$
$$m_3 - M_2 = 1\ \ 06\ .$$

The total period of variation is about $5^h\ 16^m.15$ and the range of variation about two magnitudes. The times of successive minima can be computed by adding multiples of $5^h\ 16^m.15$ to the epochs 1901 Feb. 20 $7^h\ 57^m$ and $10^h\ 48^m$, Paris mean time.

The light curve of Eros is thus quite similar to those of the variable stars

β Lyræ and *U* Pegasi, and the writer thinks the variation can be explained, as in the case of those two stars, upon the hypothesis of two bodies successively and reciprocally occulting each other, moving around their common center of gravity in very small, probably elliptic, orbits, the plane of which passes through the Earth. By reason of the relative displacement of the Earth and Eros the position of the plane of the orbit will change progressively with reference to us;



THE LIGHT CURVE OF EROS.

when this plane shall no longer encounter the Earth all the periodic variation of brightness will disappear and Eros will become like the other small planets. Meanwhile the details of the light curve and the relative variations of brightness will change progressively; and their continued observation will furnish important information on the causes which render so different from one another the light curves of the photometric double stars with continuous variation. The writer gives the following data concerning this unique system:

Period 5^h 16.15^m; eccentricity 0.0569; longitude of periastron from the line of nodes 162°.45; the semi-major axis is a little greater than the sum of the radii of the two bodies, supposing them to be spherical; the dimensions of the two bodies differ but little, their ratio being between 3/2 and 1; the mean density of the system is about 2.4; the two bodies are very elongated ellipsoids, the flattening of their meridional section appearing to be in the neighborhood of ½.

Apropos of these values the writer remarks that the duration of a revolution of the satellite is very near that of Phobos (7^h 39^m); the eccentricity is almost the same as that of the lunar orbit (0.0549); the mean density of the system differs little from that of Mars (2.28); the semi-major axis, expressed in radii of the planet is sensibly the same as that of Phobos, measured in radii of Mars; the oblateness obtained is above those which have been known in the solar system and even superior to those of the photometric doubles studied. These results are announced with a great deal of reserve, awaiting the results of further calculations by another method.

It may be well to call attention to the fact that the mutual occultation of two equal bodies could reduce their light by only one-half, that is 0.8 magnitude on Argelander's scale. This would seem fatal to the explanation given above, since the variation noted is nearly two magnitudes. If the two components could be assumed to be prolate spheroids, with their major axes nearly in the same straight line and three times as long as their minor axes, the explanation might possibly hold. H. C. W.

Astronomy in the High Schools.—In the scheme of studies outlined

for the high schools of the United States by the National Educational Association, there is no mention of astronomy.

[See *Report of Committee on Secondary and Higher Education*, July, 1899, Dr. Irwin Shepard, secretary, Winona, Minn.]

Does this mean that the study of astronomy is to be abandoned in the high schools of this country?

A recent writer in POPULAR ASTRONOMY says: "Of all the sciences astronomy is the most useful, and has always, even in early times, been cultivated for its utility. Consider the question of chronology—many are the disputes over the dates of ancient events that have been established probably by an appeal to astronomy. Also, the important matter of accurate time: the work of the astronomers at Washington affords direct and immediate assistance to hundreds of thousands every day throughout the country, who have engagements to meet and trains to despatch. Without the help of the astronomer, a nation cannot make accurate maps of its domain or trust-worthy charts of coast-lines.

"Then there are the vast benefits to all navigation interests, which arise from simple astronomical principles."

Professor Young in a volume written for high school pupils says: "The study of astronomy cultivates nearly every faculty of the mind—the memory, the reasoning power, and the imagination all receive from it special exercise and development. By the precise and mathematical character of many of its discussions it enforces exactness of thought and expression, and corrects that vague indefiniteness which is apt to be the result of pure literary training. On the other hand, by the beauty and grandeur of the subjects it presents, it stimulates the imagination and gratifies the poetic sense.

"In every way it well deserves the place which has been assigned to it in education."

It seems strange that, while biology, botony, physical geography, physics and chemistry are made prominent features in the new educational scheme, astronomy is displaced. An expression of opinion regarding the proposed change is desired. INQUIRER.

Second Chart and Catalogue for Observing Nova Persei.—This second chart and catalogue have been prepared for telescopic observation of the Nova. They were both made on the plan of the *Atlas Stellarum Variabilium* (Series III), except that the new star is placed 15′ south of the centre of the chart, on account of some bright stars north of the Nova, which will be needed for comparison.

An *auxiliary* chart was added to the principal one, to enable those observers who have no circles attached to their telescopes to find the Nova. They will experience little difficulty in first setting on δ Persei, which is of 3d magnitude, then passing to ψ and σ, and from there sweeping directly south along the stars indicated on the auxiliary chart, until they reach the stars Nos. 2 and 3 of the principal chart.

On this chart three divisions or squares may be distinguished as regards the *density* of the stars. The large square measures one degree in each co-ordinate, and contains all the BD. stars (except $+43°745$, which is of 10.5 magnitude). In a smaller square, which is 30′ wide and whose centre is the Nova, all stars have been entered which are visible in our twelve-inch refractor with a power of about fifty diameters, while in the central square of only 10′ width fainter stars have been added by means of a magnifying power of about 100 diameters. Great difficulty was experienced in seeing and measuring these objects on account of the brightness of the new star.

The *positions* of all the stars within the square 30′ wide have been determined by means of a semicircular glass scale, divided into parts 3′ wide, and of a chronograph. These positions are differential with regard to the Nova as zero point. From the preface to the *Atlas*, in which the details of this method are described, we only recall the statement that the right ascensions are supposed to be correct within 1^s, while the declinations may be erroneous by 0′.3 or even 0′.6. The positions of the stars outside this square have been computed from the

BD. or the AGC., assuming the position of the Nova, given in the title of the chart, to be correct for the beginning of the year 1901.

The *magnitudes* of all the stars on the chart were determined by sequences of steps, based on at least two independent estimates. The formula for transforming these steps to the BD. scale is of the same character as those in the *Atlas*. It will be an easy matter to replace it by any other process of transformation, graphical or arithmetical, when a scale of standard magnitudes is determined by photometric means. The faintest stars near the Nova could not be properly estimated on account of the brightness of the latter.

It is well to remark that only three good nights (March 7, 14, 16) were available for making this chart, and that then the Nova was brighter than 4th magnitude. Yet it has seemed better to distribute chart and catalogue as they are without delay, in order to facilitate observation. A more accurate scale of magnitudes, for the final reduction of the observations, may be determined at any future time, when the brightness of the new star shall have faded away.

JOHN J. HAGEN, S. J.

GEORGETOWN COLLEGE OBSERVATORY,
Washington, D. C., March 19, 1901.

COMPARISON STARS FOR NOVA PERSEI. CHART II.

No.	Steps.	Magn.	BD.		Δα	Δδ	Notes.
		M	M	°	m s	′	M
1	0	7.1	7.9	+ 43 730	− 2 55	+ 27.9	HP. 6.9 red
2	10	7.4	6.5	44 734	+ 1 22	+ 57.3	" 6.5
3	17	7.5	7.5	44 732	+ 1 0	+ 56.3	" 7.3
4	21	7.6	7.3	44 742	+ 3 25	+ 54.4	" 7.8
5	23	7.7	7.5	43 732	− 2 37	− 9.4	" 7.3
6	25	7.8	7.6	43 720	− 4 15	− 15.5	
7	31	7.9	8.0	43 766	+ 4 7	− 2.8	
8	37	8.1	8.4	43 728	− 3 10	+ 28.7	
9	42	8.2	8.5	44 717	− 0 41	+ 55.6	
10	46	8.3	8.9	43 726	− 3 29	+ 15.8	
11	49	8.4	8.6	43 744	+ 0 50	− 13.8	
12	52	8.5	8.7	43 729	− 3 10	+ 25.7	
13	55	8.6	8.9	44 712	− 2 32	+ 44.3	
14	59	8.7	9.1	44 741	+ 3 20	+ 41.3	
15	59	8.7	9.1	43 723	− 3 51	− 11.4	
16	61	8.7	8.9	44 721	+ 0 4	− 45.0	
17	63	8.8	8.8	43 740	− 0 7	+ 18.3	
18	65	8.8	9.1	43 746	+ 1 10	− 22.8	
19	65	8.8	9.0	44 724	+ 0 23	+ 37.8	
20	67	8.9	9.0	43 739	− 0 21	+ 4.8	
21	70	9.0	9.0	43 749	+ 1 41	− 8.4	
22	70	9.0	9.0	43 751	+ 1 50	− 17.9	
23	72	9.0	9.1	43 733	− 2 29	− 3.9	
24	73	9.0	9.0	43 748	+ 1 34	+ 20.1	
25	73	9.0	9.1	43 731	− 2 49	+ 4.9	
26	75	9.1	9.0	43 758	+ 3 1	− 9.3	
27	75	9.1	9.0	43 742	+ 0 37	+ 29.9	
28	79	9.2	9.0	43 757	+ 2 39	− 2.9	
29	79	9.2	9.1	43 741	+ 0 28	+ 19.4	
30	80	9.2	9.2	43 759	+ 3 4	+ 22.5	
31	82	9.3	9.1	43 752	+ 1 58	+ 15.0	
32	84	9.4	9.2	43 743	+ 0 43	+ 8.7	
33	89	9.5	9.4	43 760	+ 3 20	+ 3.2	

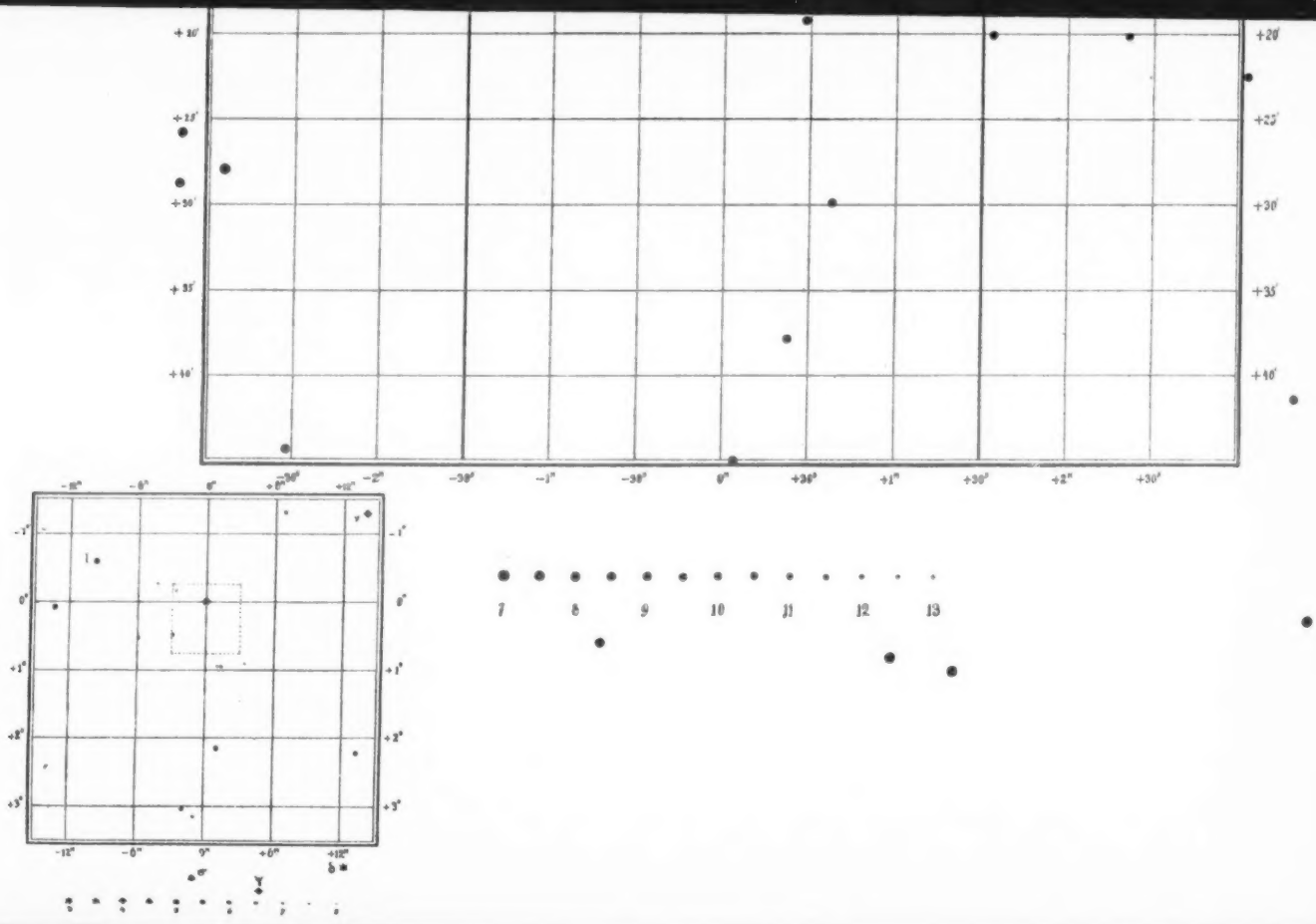


CHART II OF NOVA PERSEI. $3^h\ 24^m\ 28^s$; + 43° 33.4.

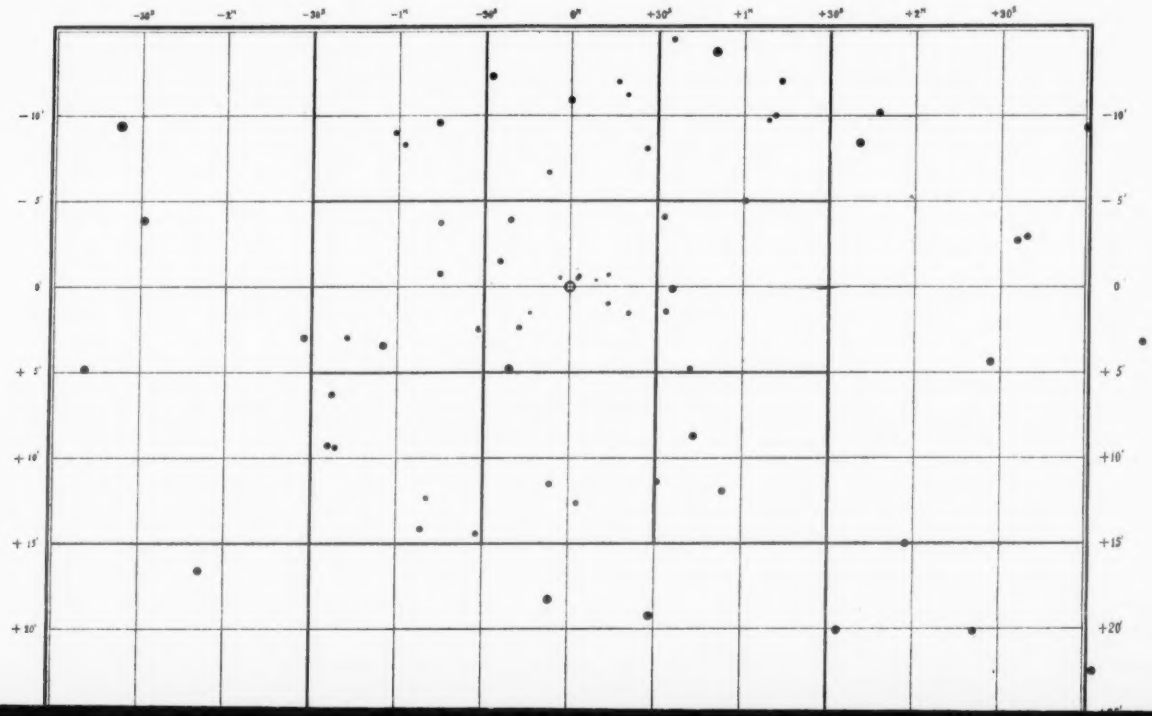


CHART II OF NOVA PERSEI. $3^h\ 24^m\ 28^s$; $+\ 43^\circ\ 33.4$.

COMPARISON STARS FOR NOVA PERSEI. CHART II.—CONTINUED.

No.	Steps.	Magn.	BD.		Δα	Δδ	Notes.
		M	M	°	m s	′	M
34	92	9.6	9.5	+43 735	−1 5	+ 3.4	
35	93	9.6	9.5	43 755	+2 27	+ 4.4	
36	94	9.6	9.5	43 734	−2 9	+16.6	
37	96	9.7	5.5	43 738	−0 28	−12.3	
38	102	9.8	9.5	43 737	−0 46	− 9.6	
39	105	9.9	9.5	43 756	+2 36	− 2.7	
40	107	10.0	9.9	43 753	+2 21	+20.1	
41	108	10.0	9.5	+43 750	+1 47	−10.2	
42	111	10.1			+0 35	+ 0.2	
43	117	10.2			−1 32	+ 3.0	
44	120	10.3			0 0	−10.9	
45	124	10.4			−1 24	+ 9.3	
46	133	10.7			−1 22	+ 6.3	
47	134	10.7			+0 54	+11.9	
48	138	10.8			+1 1	− 5.0	
49	145	11.0			−0 24	− 1.5	
50	148	11.1			+0 31	+11.4	
51	153	11.2			−1 17	+ 3.0	
52	153	11.2			−1 21	+ 9.4	
53	158	11.3			−0 32	+14.4	
54	159	11.4			−0 21	− 3.9	
55	160	11.4			+0 36	−14.4	
56	161	11.4			−0 17	+ 2.4	
57	167	11.6			−0 6	+11.5	
58	168	11.6			−0 45	− 0.8	
59	170	11.6			+1 13	−12.0	
60	171	11.7			−0 52	+14.1	
61	172	11.7			−1 1	− 9.0	
62	175	11.8			+0 3	+12.6	
63	177	11.9			−0 49	+12.3	
64	177	11.9			−0 45	− 3.7	
65	178	11.9			+0 42	+ 4.8	
66	179	11.9			+0 33	− 4.1	
67	182	12.0			−0 58	− 8.3	
68	185	12.1			+0 34	+ 1.5	
69		(12)			+0 3	− 0.5	elongated*
70	186	12.1			+1 11	−10.0	
71	193	12.3			+0 26	− 8.1	
72	196	12.4			+1 9	− 9.7	
73	196	12.4			−0 7	− 6.6	
74	199	12.4			+0 21	+ 1.6	
75	200	12.5			+0 17	−12.0	
76	205	12.6			+0 20	−11.2	
77	209	12.7			+0 13	+ 1.0	
78	212	12.8			−0 14	+ 1.6	
79	212	12.8			+0 13	− 0.7	
80		(13)			−0 3	− 0.5	
81		(13-14)			+0 9	− 0.4	

Observations of Nova Persei at Alta, Iowa.—The announcement of a new star in the constellation of Perseus reached me through the daily papers on the morning of Feb. 26th, and the same evening I secured observations of it. I found it almost exactly equal to Aldebaran in brightness, and of a bright yellowish color, but not as deep as that star in tint. Placing a 1½-inch dense flint glass prism and cylindrical lens over the eye-piece of my 4-inch telescope, I noted its beautiful spectrum. The H_a line in the red was brilliant, the yellow band bright, two or three bands in the green and one in the blue and the violet and was conspicuous, the continuous spectrum was also bright, the whole spectrum being very similar to Nova Aurigæ of 1892.

The next observation was on the 28th when the star was only as bright as β Aurigæ. It continued waning until March 15th when it was 3.9 magnitude and the bands in the green and blue were also fainter. On the following two nights the Nova appeared to me to be a trace brighter, after which date it declined again. On April 3d it was barely visible to the naked eye, perhaps owing to its deep orange-red color and low altitude at the time of observation.

On April 7th it was a difficult object to the naked eye, and through the telescope it was a deep red color and exactly the same magnitude as star No. 46 in Hagen's Catalogue given in April number of POPULAR ASTRONOMY, which is 5.7 mag. The following night I was surprised to see it again plainly visible to the naked eye even through the haze, at 10:00 o'clock and estimated its brightness at about 4th magnitude. Its color also was a brighter orange-red, only one bright band, viz: the Hα in the red was conspicuous.

The following are my estimates of the Nova's brightness on the dates indicated:

1901.	Magnitude.	Remarks.
February 26	1.0	Same as Aldebaran.
" 28	2.0	Equal to β Persei.
March 1	2.3	Brighter than δ Persei.
" 4	2.7	
" 5	2.7	
" 6	3.1	Exactly equal to δ Persei.
" 10	3.1	
" 15	3.9	Same as ν Persei.
" 16	3.7	Trace brighter.
" 17	3.7	
" 21	4.2	Same as *l* Persei.
" 22	4.0	Seems brighter.
April 3	5.6	
" 7	5.7	Same as No. 46 in Hagen's Catalogue.
" 8	3.9	Same as ν Persei.

ALTA, Iowa,
April 9th, 1901.

DAVID E. HADDEN.

Nova Persei, No. 2.—The early observations made here, of the new star in Perseus, are described in Circular No. 56. This star may be designated Nova Persei, No. 2, to distinguish it from the star in R. A. $1^h\ 55^m.1$, Decl. $+\ 56°\ 15'$, which appeared in this constellation in 1887. A photograph of the vicinity of the Nova, taken with the Cooke lens on February 19, 1901, with an exposure of 66^m, beginning at $11^h\ 18^m$ G. M. T., is shown in Figure 1.* For comparison, a similar photograph taken on February 26, 1901, with an exposure of 56^m, beginning at $14^h\ 32^m$ G. M. T., and showing the Nova, is given in Figure 2.*

The accompanying plate gives enlargements, made with a moving plate, of three photographs of spectra taken with the 11-inch Draper telescope. The first

* See Circular for figures and plate.

represents the new star in Perseus taken on February 22, 1901, with an exposure of 40^m, beginning at 16^h 08^m G. M. T. The second represents the same star taken on February 24, 1901, with an exposure of 66^m, beginning at 14^h 43^m G. M. T. The change from the first form of spectrum to the second must have been very sudden. A plate taken through dense clouds on February 23, with an exposure of 29^m, beginning at 11^h 37^m G. M. T., showed but little change, while Professor Vogel has announced that a photograph taken the same night shows a spectrum traversed by several broad, hazy bands. The third spectrum represents Nova Aurigæ, taken on February 5, 1892, with an exposure of 123^m, beginning at 11^h 09^m, G. M. T. It will be seen that the second and third spectra closely resemble each other, but that the lines in Nova Aurigæ are much narrower and more sharply defined. The later photographs of the spectrum of the new star in Perseus show numerous changes, the dark lines and the edges of the bright lines being, in many cases, well defined. EDWARD C. PICKERING.

HARVARD COLLEGE OBSERVATORY,
Circular No. 57, March 15, 1901.

NOVA PERSEI.

Star.	Y.	M.	D.	H.	M.	Jul Day.	Comparison with Naked Eye.	Color.
Nova Persei	1901	2	24	6	30	2415440	Var. 3 grades fainter than Capella	
"	"	"	"	7	50	"	Capella 3½ v 5 Pollux	Orange
"	"	2	25	6	50	2415441	Betelgeuse 2 v 2 Pollux	"
"	"	"	"	9	50	"	Betelgeuse 1½ v 2 Pollux	"
"	"	2	26	6	50	2415442	Pollux 1½ v 2½ Castor	"
"	"	"	"	8	40	"	Pollux 1½ v 2½ Castor	"
"	"	"	"	9	30	"	Pollux 1½ v 3 Castor	"
"	"	"	"	10	40	"	Pollux 1½ v 3 Castor	"
"	"	2	27	5	55	2415443	Castor 1½ v 1 α Persei, twilight	"
"	"	"	"	8	0	"	α Persei 1 v 1 α Arietis	Red
"	"	3	6	6	50	2415450	Var. ½ grade brighter than γ Persei	"
"	"	"	"	8	50	"	γ Persei ½ v ½ δ Persei	"
"	"	"	"	9	40	"	γ Persei ½ v ½ δ Persei	"
"	"	3	7	6	55	2415451	ζ Persei 1 v 1 γ Persei	"
"	"	"	"	8	10	"	ζ Persei 1 v ½ γ Persei	"
"	"	"	"	9	5	"	ζ Persei 1 v 1 γ Persei Cloudy.	"
"	"	3	11	9	15	2415455	Var. ½ grade brighter than ρ Persei	"
"	"	3	12	7	10	2415456	δ Persei 1 v 1 ρ Persei	"
"	"	"	"	8	20	"	δ Persei 1 v 1½ ρ Persei	"
"	"	"	"	9	40	"	δ Persei 1 v 1½ ρ Persei	"
"	"	3	17	7	10	2415461	ρ Persei 1 v 2 κ Persei	
"	"	"	"	8	40	"	ρ Persei 1 v 1½ κ Persei	Red
"	"	3	18	7	55	2415462	ρ Persei 1 v 1 κ Persei	
				7	10 to			
"	"	3	19	7	20	2415463	This object has decreased greatly in brightness during the past 24 hours. I estimate it at 5½ mag. tonight and fiery red in color.	

F. E. SEAGRAVE.

Nova Persei.—I have been much interested in the new star in Perseus, and surprised that the accounts from different observers seem to indicate that it was never of greater brilliancy than Capella. I saw in the morning paper of Feb. 23d

(Saturday) notice of the discovery of the new star, reported by Harvard as of the first magnitude the evening before, and invisible on the 19th. Early that evening it was cloudy, but at midnight it was beautifully clear, and the Moon having just set the new star shone forth in all its glory, and was certainly a trifle brighter than Capella, and a good match for it in color. The only star in the heavens brighter than the Nova was Sirius.

As the Nova was very noticeably less brilliant the next evening (Feb. 24th) being then no brighter than Capella, if as bright, is it not quite possible that those observers who reported the Nova as less brilliant than Capella on the evening of the 23rd, observed it later than midnight, or else enough earlier to have it somewhat obscured by the Moon, which was nearer to the Nova than to Capella? The light of Nova varied so rapidly that I am not inclined to question my observation in comparison with Capella at midnight, but am ready to believe that it was brighter at that moment than an hour earlier or later. My observation was from midnight to 12:20 A. M. Central standard time. While my eyes are not especially trained for star magnitudes, I have had some experience in photometric work, and in estimating relative brilliancies. Nova seemed to twinkle more than Capella, which was of course nearer the zenith. MORGAN BROOKS.

THE UNIVERSITY OF NEBRASKA, Lincoln, Neb.

Nova Persei.—The announcement of Anderson's discovery of this new star was received in the daily newspapers and I did not observe it until March 5, and only at occasional intervals since owing to cloudy weather. The star was easily identified by its brightness in the midst of Perseus. Its light was about midway between Algol (normal) and ι Aurigæ an the first night and rapidly declined so that on March 19, 22 it was difficult, in fact too faint to make any reliable naked eye comparisons, and then by March 31 it had brightened so as to be easy of comparison in the moonlight. My observations are all naked eye as follows:

1901, March	5.54 (G. M. T.)	β Persei 5 v, v 6 ι Aurigæ.
	6.55	ι Aurigæ 4-5 v, v 1-2 ϵ Persei.
	7.54	ι Aurigæ 5 v, v 4 ϵ Persei.
	17.58	δ Persei 5-6 v, v 5 ν Persei.
	19.6	Very much fainter than ν Persei.
	22.6	" " " " " "
	31.57	ν Persei 4 v, v 2 ξ Persei.
April	9.56	o Persei 2 v, v 6-7 ι Persei, ξ Persei 7 v.
	11.56	ι Persei 6-7 v.

WM. E. SPERRA.

BARBERTON, Ohio, April 14, 1901.

A List of Stellæ Novæ and of So-called "New Stars."—The recent discovery of a remarkable new star by Dr. Anderson of Edinburgh, Scotland, has again directed special attention to this curious class of celestial bodies. As an aid to the readers of POPULAR ASTRONOMY who may wish to learn more about such stars by reading the various descriptions of them which have been printed from time to time as each new one appeared, I have compiled the following list. It contains all stars which have been claimed to be "new stars" so far as I can find in the books of the library which is at present accessible to me. Many of these claims have not been substantiated: particularly in the cases of appearances earlier than 1572 A. D. The reports are often vague, and as applicable to comets (with or without tails) as they are to genuine *novæ*. Even in the case of some of the most recent, it has been hard to draw a sharp distinction between

variable stars of long period and *novæ*, so that the classification of several of these is debatable. Two good books of general reference for brief descriptions of nearly all these stars, are:

Cosmos: A Sketch of a Physical Description of the Universe, by Alexander von Humboldt. In Vol. III, chap. IV. This work has been translated by E. C. Otte and is published by Harper Brothers, New York.

Astronomy: By Clerke, Fowler and Gore. Section IV, pp. 477-497. Published by Appleton & Co., New York.

No.	Year.	R. A.	Decl.	Name.	Reported by	Prob'ly a
		h	°			
1	134 BC	16	− 25	Star of Hipparchus	Pliny	Nova
2	76 BC	11 30	+ 60	.....	.....	.....
3	101 AD	10	+ 20	.....	.....	.....
4	107	7 10	− 27	.....	.....	.....
5	123	17 10	+ 14	.....	Ma-tuan-lin	.....
6	130?	.....	.....	.....	.....	.....
7	173	14 20	− 60	.....	Ma-tuan-lin	Nova
8	329?	.....	.....	.....	.....	Misprint
9	369	.....	.....	.....	Ma-tuan-lin	.....
10	386	18 30	− 27	.....	Ma-tuan-lin	.....
11	389	19 50	+ 10	(or 388 or 398 AD)	Cuspianus	Nova
12	393	17 30	− 40	.....	Ma-tuan-lin	.....
13	561	10 55	− 18	R Crateris??	.....	.....
14	827?	17	− 30	.....	Albumazar	.....
15	829	7 40	+ 5	.....	.....	.....
16	945	23 50	+ 65	.....	Leovitius.....	Comet
17	1011	18 45	− 27	.....	Ma-tuan-lin	.....
18	1012	2	+ 20	(or 1006? AD)	Hepidannus	Nova
19	1054	4	+ 15	.....	.....	.....
20	1139	14 10	− 10	.....	.....	.....
21	1203	16 40	− 40	.....	Ma-tuan-lin	.....
22	1230	17 40	− 10	.....	Ma-tuan-lin	.....
23	1264	23 40	+ 65	.....	Leovitius	Comet
24	1572	0 19	+ 63 35	Tycho's: Pilgrim star	Gemma	Nova
25	1578	.....	.....	.....	Ma-tuan-lin	Comet?
26	1584	15 50	− 25	.....	In China	.....
27	1600	20 14	+ 37 43	P Cygni	Jansen	Variable
28	1604	17 24	− 21 23	Kepler's	Brunowski	Nova
29	1609	.....	.....	.....	Ma-tuan-lin	*of 1604?
30	1670	19 43	+ 27 4	11 Vulpeculæ	Anthelm	Nova
31	1848	16 54	− 12 44	— Ophiuchi	Hind	Nova
32	1860	14 9	+ 19 32	T Bootis	Baxendell	Nova
33	1860	16 11	− 22 44	T Scorpii	Auwers	Nova
34	1863	16 16	− 17 38	U Scorpii	Pogson	Nova
35	1866	15 55	+ 26 12	T Coronæ: Blaze star	Birmingham	Nova
36	1876	21 37	+ 42 23	Q Cygni	Schmidt	Nova
37	1885	0 37	+ 40 43	S Andromedæ	Hartwig	Nova
38	1887	1 55	+ 56 15	W Persei	Fleming	Nova
39	1892	5 25	+ 30 22	T Aurigæ	Anderson	Nova
40	1893	15 22	− 50 14	R Normæ	Fleming	Nova
41	1895	11 3	− 61 24	RS Carinæ	Fleming	Nova
42	1895	12 28	− 54 6	U Centauri	Fleming	Nova
43	1895	13 34	− 31 8	Z Centauri	Fleming	Variable
44	1901	3 24	+ 43 34	? Aurigæ	Anderson	Nova

HERMAN S. DAVIS.

INTERNATIONAL LATITUDE OBSERVATORY,
Gaithersburg, Maryland, March 14, 1901.

Pleasures of the Telescope,* by Serviss; D. Appleton & Co., pp. 200. This book is a worthy supplement of "Astronomy with an Opera-Glass," by the same author. After an opening chapter devoted to the selection and testing of a telescope Mr. Serviss describes in a popular and interesting fashion the chief objects in the sky which may be studied by means of a small telescope. He assumes that the telescope is not provided with graduated circles. Hence it is necessary for its user to find objects by knowing where they are situated among the stars. Twenty-six full page maps of different parts of the sky are therefore scattered through the text. They show not only the naked-eye stars, but the positions of such other objects (double stars, colored stars, clusters and nebulæ) as are to be telescopically examined. Each of the objects studied is described in that pleasing and attractive style of which which Mr. Serviss is a master. Touches of fancy and outbursts of enthusiasm enliven description otherwise prosaic.

About two-thirds of the book is thus devoted to objects fixed in the sky. The planets and the Moon then claim each a chapter; the face of the Moon is shown in four very plain maps. The book is concluded by a discussion of the question whether there are planets attendant on stellar suns. H. A. HOWE.

Astronomy in the 20th Century.—Those who think and write on astronomical themes sometimes indulge somewhat in imagination, and wonder what will be the things known and the methods of work in astronomy of one hundred years in the future. Mr. Garrett P. Serviss, of New York, has recently written suggestively on this point. He says:

What gravitation is, and how the heavenly bodies attract one another across empty space, seems about to be answered. Professor Fessenden, in a series of researches that will enable the astronomers of the year 2000 to stand on an elevation now unattainable, is corrrelating gravitation with electric phenomena which affect the ultimate particles of matter.

But there is perhaps a more brilliant fore-glimpse of the future of astronomy to be obtained when we consider the recent progress in our knowledge of invisible types of radiation. It is probable that by the year 2000 astronomy will virtually have developed for man a new sense through which will be revealed to him another phase of the universe as intimately associated with his being and destiny as is the visible phase with which we are familiar. By that time the curtain of mystery which now covers those waves of energy that, impressing us neither as light nor heat, sweep continually in from star-sprinkled space may have been lifted.

Such discoveries will require a new type of instruments. There will come an evolution of the telescope into something far more potent than the giant glasses of our day. A hundred years ago all effort was concentrated upon increasing the visual power of telescopes. The only thought was how to make them see deeper into the heavens and see more. In the course of the nineteenth century that effort has resulted in multiplying the power of the human eye about 40,000 times. It has made man potentially a colossus more than a thousand feet tall, for a person whose eye could grasp as much light as the Paris telescope would have to be magnified two hundred times in all of his dimensions.

And yet this astronomical Frankenstein cannot see the things that the new astronomy will have to deal with. If the power of the eye were increased a

* If this review had been earlier received it would have been included in Mr. Howe's article on "Astronomical Books for the Use of Students," printed elsewhere in this number.

million times it would not suffice. With eyes as big as the Moon we could not see those thousands of strange spiral nebulæ that hang like garlands in black space and whose presence is just beginning to be detected by other means.

In the year 2000 astronomers will know what else those nebulæ do besides imprinting their images on photographic plates—will know whether their mysterious radiation has other powers as yet undreamed of. By that day photography will have aided us to create a new sense, of our own invention, superposed on the sense of sight, and then it will be time to test Mr. Tesla's idea that if we cannot see the inhabitants of other worlds, at least we can communicate with them. Imagine a person blind from birth suddenly endowed with full powers of sight. The transformation and expansion that the world would undergo for him may serve as an image of the revelation that the year 2000 may have in store for the astronomers who have mastered the secrets of invisible radiation. The telescope of that age will be made not for seeing, but for transcending sight.

Yet I think that the next century will witness an enormous development of our powers of seeing also. The telescopic colossus will continue to grow until his head virtually overtops the Alps. Following the lines laid down in the construction of the Paris telescope—a giant too unwieldy to stand upright, but, like Anteus, gathering power from contact with the Earth—it seems possible to have object glasses, or reflectors, several yards in diameter. The present tendency to turn mountain summits into Observatory sites is also likely to continue, and by 2000 A. D., with the aid of mountain railroads like that which is now piercing the vitals of the snowy Jungfrau, gigantic telescopes may question the heavens from a hundred lofty peaks.

We have also just beheld the beginning of the use of balloons for astronomical observations. The air ship of the twentieth century may find one of its most useful applications in carrying the astronomer and his instruments a little closer to the stars.

Shall we form acquaintance with the inhabitants of other worlds in the year 2000? If I were alive at that time, and privileged to use some of the instruments of discovery that will then be in existence, I would try their power upon the planet Venus. I would not expect actually to see people there, but if I perceived some unquestionable proof, or token of their existence I would feel that astronomy had performed its part and vindicated its claim to be regarded as the leader of human science.

The Alvan Clark & Sons Corporation, Telescope Makers.—The business of Alvan Clark & Sons, manufacturers of astronomical telescopes, has been incorporated under the above title.

The corporation retains the expert services of Mr. Carl A. R. Lundin, who for the past twenty-seven years has been identified with the management of the business.

Enlarged capital and additional facilities will increase the efficiency of the factory and prompt attention to all orders is assured. While the corporation neither expects nor desires to compete with work of inferior character, it is in a position to produce the best results modern methods can accomplish and fully maintain the reputation of the Clark telescope, with which practically all the important astronomical discoveries for the past fifty years have been made.

These makers have recently completed for the University of Maine, at Orono, Maine, an 8-inch equatorial telescope, fully equipped, with clock-work and filar micrometer. Also a 7½-inch with the same accessories for Mr. George Agassiz.

They are now equipping the Observatory on Mt. Tom, owned by the Holyoke Street Railway, with several telescopes, one of the smaller ones being a 3-inch binocular, with prism erecting eyepiece.

Prices and estimates, both for new work or proposed alterations, will be submitted on application.

A New Text-Book of Astronomy.—This new book, prepared by Professor George C. Comstock, Director of Washburn Observatory of the University of Wisconsin, concentrates attention on those parts of the science that possess special educational value. This aim involves experimental work that will encourage simple observation so necessary for best uses of even a limited knowledge of elementary astronomy. So Professor Comstock begins with the ideas of a linear and angular measurement, and figures and illustrations are given that will easily and directly lead the learner to value observation, and give him interest in getting such knowledge.

In the next chapter the stars and diurnal motion are considered and some apparatus easily devised for naked-eye observation, is beautifully figured. Also suggestions are offered for the use of a small camera, by which star trails in the north polar regions are secured, that ought to interest any student only a little in practice in photography. These simple exercises lead the student to recognize the diurnal motion of the constellations and to more detailed study of the uranography of the sky. In this connection the student is given exercises in sketching the outlines of the constellations, one of the best means possible to make his knowledge however small, of definite and special value. Such work will not be carried too far. The probability is that far too little of it will be done for the students own greatest advantage.

The topics discussed in the following chapters are celestial mechanics, the Earth as a planet, the measurement of time, eclipses, instruments and the principles involved in their use, the Moon, Sun, planets, comets and meteors, fixed stars, stars and nebulæ and growth and decay.

The strong points of this excellent book are the plain, direct way of stating the principles and latest facts known to astronomy, the many new and neat illustrations, and plates, and the fresh, apt and original way of popularizing the elements of astronomy without appreciable loss to science or fact.

The book is published by the Appletons of New York, and it is beautifully done, without any attempt in useless ornament. Teachers certainly will be interested in this new book.

Correction.—In the article on "Ancient Eclipses and Chronology" in the April No. the types in two places said the "criticism of Sir John Herschel," instead of "criterion of " etc. R. W. M.

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